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RELATION OF THE MINING SCHOOL TO THE MINING INDUSTRY[1]

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It is taken for granted that the mining industry is the chief thing and that the school exists to help the industry. A difference of opinion may exist as to how this should be done.

The mining industry has such a strong bearing on the welfare of the community that it is well to dwell upon this relationship a moment before taking up the main thread.

The miner brings the ores to the surface; the smelter separates the metals — metals without which there can be no advancement in the community, no civilization.

What did the stone age man have? A stone hammer, a stone knife, a stone arrowhead, a tent of skins. He had advanced as far as he could without metals. We are so accustomed to use metals and articles manufactured of metals, or by means of them, that we do not think of the immense advance that has been made in consequence of the work of the miner and metallurgist, and of the wonderful age in which we live.

If we look about this room every metallic object in sight has been made from ore got by the miner and refined by the smelter. Every

[1] Read before the American Mining Congress at Joplin, Missouri, November 11, 1907.

object in wood, glass, pottery, plaster, cement, or other material than metal has been gathered, shaped, and finished by tools of metal. And again, the business of mining and metallurgy furnishes a great field for gaining a livelihood. Great numbers of men are employed in the ranks of labor and of the skilled mechanic; considerable numbers also in engineering, management, financing of mines; also in the mercantile pursuits to furnish supplies. Finally, as an investment of funds, the successful mine is among the most profitable of investments, and the unsuccessful mines may be no worse for the stockholder than the unsuccessful railroad or manufactory.

The points of contact between the community and the mining industry are then varied in kind and many in number. For economy in the world's work, for the best results in quickest time, all forces tending toward the same end should work in harmony, each doing its own part. This is the case with the mining industry and the mining school.

Mining plants should be ready to supply to students certain necessary experience which the school cannot give — hence the need of mine practice; but they cannot do the whole work without great waste of time — hence the need of the school training. There should be a cordial relationship between school and mine.

The school asks the mining industry to take its pupils and be patient with them for a little time until they acquire the experience with men in command and men employed — things that no school can teach. A few vacation months at a mine, mill, or furnace is worth a great deal to help a student appreciate the value of his school work, to clinch his knowledge, to make it a useful tool, and to work off his crudity.

The universal verdict is that a student leaving a school should spend a year or more at work at mines or furnaces, doing laborers' or mechanics' work. He not only gains by contact the knowledge of things which the school failed to give him, but, and still more important, he gains knowledge of men. A man to direct others must know what the other man is thinking of. The young man who began as a laborer knows this from his own experience. The young man who did not so begin is at a great disadvantage. Therefore we ask the works and mines to have a little patience with the young beginners just out of school. Many works are already doing this in a very liberal way. And I wish here, in behalf of the schools, to present our thanks to those in charge

of the mining industry for the fine way they are doing this. We ask, further, that those in charge of industry forgive the occasional misfit which the young schoolman makes, and that they do not charge off his misdemeanors and mistakes as a universal attribute of schoolmen.

Besides the knowledge of things by contact that a student can learn at the works, the sense of responsibility he acquires is of immense value. It is impossible to give in the school the sense of impending fate which impresses facts on the brain in mines and furnaces. A furnace man must get his 300 tons a day smelted or lose his job. A miner must get his pump running in three hours or the pump will be drowned and the mine flooded. This kind of active work and experience is a great teacher.

What, now, may the school do for the works in return for favors received? Those in active work, with the constant and incessant demands upon them, have little time to investigate problems and to seek for the underlying principles on which the most perfect solution may depend, or to find what others at a distance are doing in the same line; and if they are self-made men they are probably wise in experience but weak in mathematics. In most mines there have been short periods of depression because of failure to grasp some salient point which a trained engineer would have seen.

The school teaches the alphabet of machinery and processes and fundamental knowledge, just as useful here as the real alphabet is in looking out words in a dictionary. The mining school cannot give the experience, but can give the training in mathematics, physics, chemistry, and drawing; and it can give the pupil access to the accumulated fund of professional methods of all time. This leads us up to the school's main duty to the mines and works. If a school can inspire enthusiasm for the profession in its pupils, and can bring the pupils to the point where they have love of knowledge, love of accuracy, love of industry, it has led its pupils to a point where they are ripe to become engineers, for they will be naturally seeking problems to solve and solving problems when found — problems in excavating, in sorting, in tramming, in hoisting, in dealing with men; problems in moving materials, in concentrating ores, in economy of waste, in re-treating waste, in dealing with the market, in handling the property to the advantage of the owners, and, indirectly, of the community.

The student must acquire a love of knowledge, a love of accuracy, and a love of industry. We expect the school to develop this in him.

How can the school do this? It can only do it by making the problems the school sets before the pupil real, live, interesting ones. A real problem as new to the teacher as to the pupil has the greatest power to awaken enthusiasm in the pupils. Every small problem solved in the school laboratory whets the appetite for greater ones in the field.

The school has to make things real to most of its pupils, who have never seen a mine. The pupil who goes to the school from the mining region, while he is an apt pupil and interested in the profession, is unbalanced by giving more value to the details in his own district than to fundamental principles. He must be balanced up by showing him the value of fundamental principles and the differing practice of other districts. The school must be organized to help both kinds of students. One of the best things the mines and works can do for the schools is to let the teachers know some of the real problems with which the profession is struggling. This can well be done when the teachers bring their students on visits. The teachers can get in this way into the spirit of the game and carry back problems to work over at the school, thus gaining inspiration for their work which they pass on to their students. Furnish them specimens, samples, drawings, photographs. Students become immensely interested in actual needs if something they do is going to count. It makes the profession a real, living interest to them.

The school contributes to the success of the mining industry; the mining industry is vital to the success of the community, and therefore the community must support the mining school.

CONTRIBUTION FROM THE
SANITARY RESEARCH LABORATORY AND SEWAGE EXPERIMENT STATION
OF THE MASSACHUSETTS INSTITUTE OF TECHNOLOGY

INVESTIGATIONS ON THE PURIFICATION OF BOSTON SEWAGE IN SEPTIC TANKS AND TRICKLING FILTERS (1905-1907)

BY C.-E. A. WINSLOW AND EARLE B. PHELPS

I. RESULTS OF PREVIOUS INVESTIGATIONS

THE Sanitary Research Laboratory and Sewage Experiment Station of the Massachusetts Institute of Technology was founded in 1902 by an anonymous donor for the purpose of making experiments upon improved methods of sewage disposal, especially those adapted to large cities. A large part of the work of the staff has been devoted to the study of the more purely scientific problems — chemical, bacteriological, and hydraulic — which underlie the practice of sewage analysis and sewage purification. We have carried on, however, along with these theoretical investigations, an experimental study of the immediate local problem of sewage disposal, as it is certain some day to confront the city of Boston.

The sewage of the Metropolitan district of Boston is at present discharged, untreated, into the waters of the harbor at three different points. The main outfall sewer of the north district carries some fifty million gallons daily, and discharges continuously off Deer Island. The sewage from the high level district passes out to Peddock's Island, near the southeastern limit of the harbor; this amounts to about twenty million gallons. The main outfall of the south Metropolitan district is at Moon Island, nearer the centre of the harbor, and here the sewage is stored in masonry tanks and discharged only on the turn of the tide. The daily flow in this sewer is in the neighborhood of one hundred million gallons. The Massachusetts State Board of Health investigated the condition of Boston Harbor in 1905 (Goodnough, 1906), and found no serious damage from this method of disposal. The town

of Wellesley has, however, recently been refused admittance to the Metropolitan system from fear of overtaxing the purifying power of the harbor (Wellesley, 1907);[1] and it can scarcely be doubted that the progressive increase of population within the drainage district itself will ultimately bring the problem of sewage purification to the fore. The present agitation in regard to the pollution of New York Harbor (Whipple, G. C., 1907) under somewhat similar conditions is an indication of what must some day be expected in Boston.

Under these circumstances it is important to form a general idea beforehand of what a proper purification of Boston sewage will involve; and the investigations at the Sanitary Research Laboratory have reached a point at which this can approximately be determined. It should be understood that neither state nor municipal authorities are responsible for the conclusions which follow. The investigations here reported proceed wholly from the Sewage Experiment Station of the Institute, and deal with a coming problem, not a present one. It is hoped, however, that they may yield data of importance in determining the feasibility of a disposal project when the time for installing one shall come, and offer some guidance as to its probable final form.

The first essential in planning for sewage disposal is a knowledge of the special characteristics of the sewage in question. In a previous communication (Winslow and Phelps, 1905) we have discussed this point somewhat fully. The sewage of the south Metropolitan district, with which we dealt in our experiments, is that which flows from the combined system of the city of Boston proper. It is a typical American domestic sewage, of average strength, and in 1903 morning samples showed an average of about six parts per million of nitrogen as albuminoid ammonia, eighteen parts of nitrogen as free ammonia, and forty-five parts of "oxygen consumed." Suspended solids were at this time somewhat under 150 parts per million. We have pointed out in the paper above cited that the average analysis of the whole twenty-four hours' flow was about 80 per cent. as strong as the morning sewage.

A preliminary series of investigations covering the various methods of purification in common use was carried out from 1903 to 1905. Septic tanks, contact beds, sand filters, and trickling filters were studied, each unit being a cypress tank of 72 to 96 cubic feet capacity, and the results have been fully presented in a previous communication

[1] It is understood that this action was taken in view of the fact that Wellesley lies outside the area previously fixed upon as properly tributary to the Boston outfall.

(Winslow and Phelps, 1906). These studies led to certain general conclusions which may be summarized as follows:

It will be necessary in any treatment to screen out large floating bodies and to settle out mineral detritus. This process should be limited to a sedimentation of a few minutes. Under such conditions the settled material amounts to about 16,000 pounds (.65 cubic yard) per million gallons of sewage, and is of such a character that it may be spread out on land without fear of nuisance.

A further removal of the suspended organic matter may be effected, if desired, by treatment in the septic tank. In our experiments an open tank operated as well as a closed tank. Varying the storage period from twelve to forty-eight hours produced no difference in the effluents which was measurable by analytical results. The tanks studied removed nearly two-thirds of the suspended matter and yielded an effluent which was clear, but much darkened by sulphides. The tanks on an average received fifty pounds of nitrogen as albuminoid ammonia (dissolved and suspended), of which thirty pounds were discharged in the effluent, fifteen to seventeen pounds decomposed, and three to five pounds stored as sludge. In the decomposition of sludge the length of the septic period was of great importance. The amount of organic solids stored, undecomposed, per million gallons of sewage passed was twice as great with a forty-eight-hour period as with a twenty-four-hour period and four times as great as with a twelve-hour period.

Under the conditions of these experiments, crude Boston sewage was successfully filtered through a 2-foot bed of sand with an effective size of .14 mm., at a rate of .4 million gallons (400,000 gallons) per acre per day, divided into four doses in the twenty-four hours. Such high rates should not be expected in actual practice, with outdoor beds, particularly during the winter months. In communities with limited sand areas much might be accomplished, however, by frequent cleaning of the surface of the beds; and it is interesting to know that with care in construction and operation the sand filter may be efficient at higher rates than have been generally advocated. The effluents obtained from the sand beds in these experiments were clear, bright, and well purified. Preliminary septic treatment for twelve or twenty-four hours did not improve the effluents obtained with sand filtration, although it made the care of the surface of the beds somewhat easier.

It was found that crude Boston sewage could be treated in single-contact beds of fine stone (½ inch in diameter) at a rate of about

1.2 million gallons per acre per day. The effluent, though only partially purified, was generally so stable that it could be discharged into a considerable volume of water without any tendency to create a nuisance. The beds clogged rapidly and the surface needed much attention. The double-contact system of treatment, in primary beds of 2-inch material and secondary beds of ½-inch material, yielded a fairly well purified and

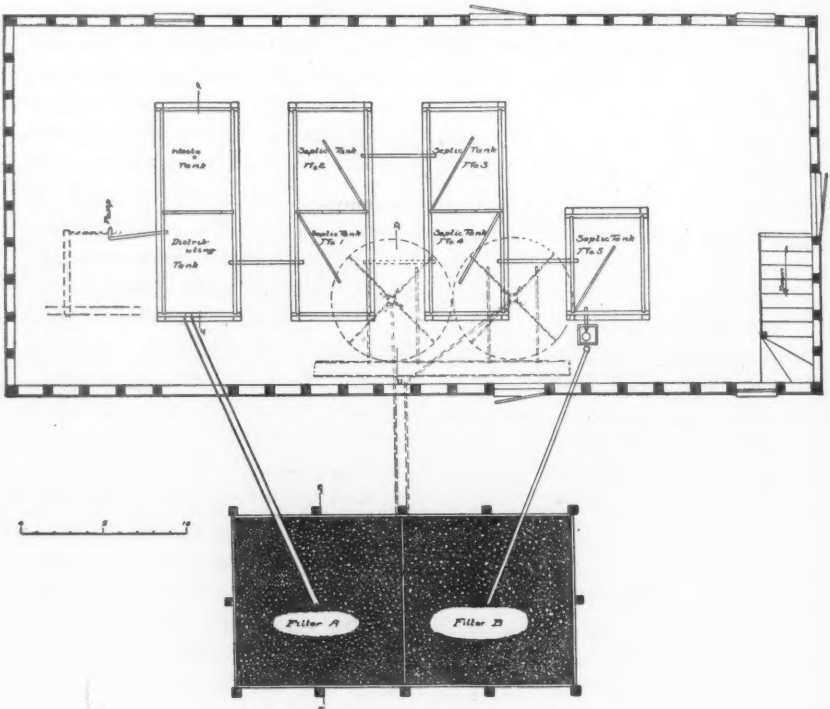


FIG. 1.—PLAN OF EXPERIMENTAL PLANT

stable effluent at a rate, on the combined double system, of about 0.7 million gallons per acre per day, with beds 6 feet deep. This system clogged much less seriously, but nevertheless lost sufficient capacity to require renewal every few years. Preliminary septic treatment obviated this loss of capacity to a considerable extent.

Experiments with continuous, trickling, or sprinkling filters showed results equal to those obtained with the double-contact system at much

higher rates, and suggested that this method would probably prove the most practical of all. Three such tanks were studied, one from 1903 on and the other two in 1904 and 1905. They were operated at rates between 1.5 and 2.5 million gallons per acre, producing turbid but fairly stable effluents, and were entirely free from surface clogging. To base conclusions as to the efficiency of trickling filters upon tanks only 16 square feet in area, dosed with tipping buckets and operated under

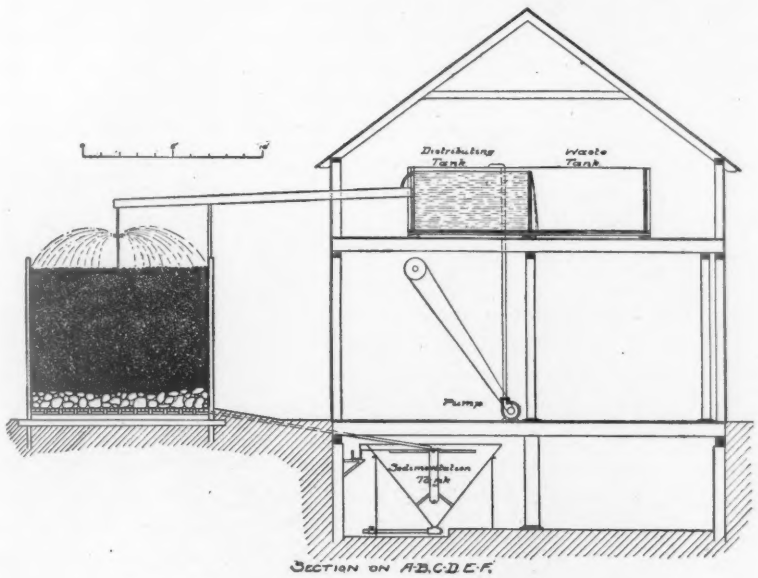


FIG. 2.—SECTIONAL ELEVATION OF EXPERIMENTAL PLANT

cover, seemed, however, unwise. For such a general survey as was contemplated in our preliminary work, and particularly for studies of contact beds, small indoor filters are of value; but the two important points in the operation of the trickling filter are the system of distribution and the effect of winter conditions, neither of which can be studied on a small scale. We therefore constructed in August, 1905, an outdoor filter of adequate size, which has been successfully operated for nearly two years; this has yielded results which we believe to be representative.

II. Description of the Experimental Plant

The Sewage Experiment Station of the Massachusetts Institute of Technology is situated in the southeastern portion of the city of Boston, near the corner of Albany Street and Massachusetts Avenue. It includes a small, two-story laboratory building, a two-story tank house, and the trickling filter. Septic tanks and sedimentation basins are placed inside the tank house. The general arrangement of the tank house and filter is shown in Figures 1 and 2.

Sewage for the use of the station is obtained from the 9-foot trunk sewer of the Boston Main Drainage Works at a point where there is a flow of some fifty million gallons a day from a contributing population of 250,000. It is raised by a 4 × 6 Warren duplex pump, being roughly settled on the way by passage through a grit chamber, 19 inches in diameter and 16 inches deep, fitted with a screen whose bars are ½ inch apart. The sewage is then raised, without further sedimentation, by a ¾-inch centrifugal pump to the distributing tank, shown in the plan and section, Figures 1 and 2. No sludge was removed from this tank, and the inflow was kept always in excess of the outflow, a constant head being maintained by wasting over a 36-inch weir at one end. From the opposite end of the distributing tank sewage flowed to one of the trickling beds, filter A, over a 1-inch brass weir, the crest of which could be raised or lowered by a micrometer screw. By regulation of this crest in relation to the constant height on the waste weir it was possible to obtain any desired flow on the filters. A depth of about 1 inch on the small weir corresponded to 200 gallons per hour, or 2,000,000 gallons per acre per day, the rate in use for the past two years.

From one side of the distributing tank sewage flowed continuously through a short length of 2½-inch iron pipe to the first of the septic tanks. These were open cypress tanks, 6 × 4 feet × 3 feet deep, connected in series by 2½-inch iron pipe.

The general arrangement of the septic tanks is indicated in Figure 1. Only Nos. 1, 4, and 5 were used during the first twelve months of the investigation. In October, 1906, the direct connection between 1 and 4, and 4 and 5, was cut off and Nos. 2 and 3 brought into the series. The distributing tank and all five septic tanks have since that time been in open connection, the level in all being controlled by the large waste weir of the distributing tank. The septic tanks were

provided with wooden baffles, arranged as shown in Figure 1. The total capacity of the septic system was equal to twelve hours' flow, and its division into five separate tanks made it possible to study successive stages in the septic process. From the last tank, a 1-inch

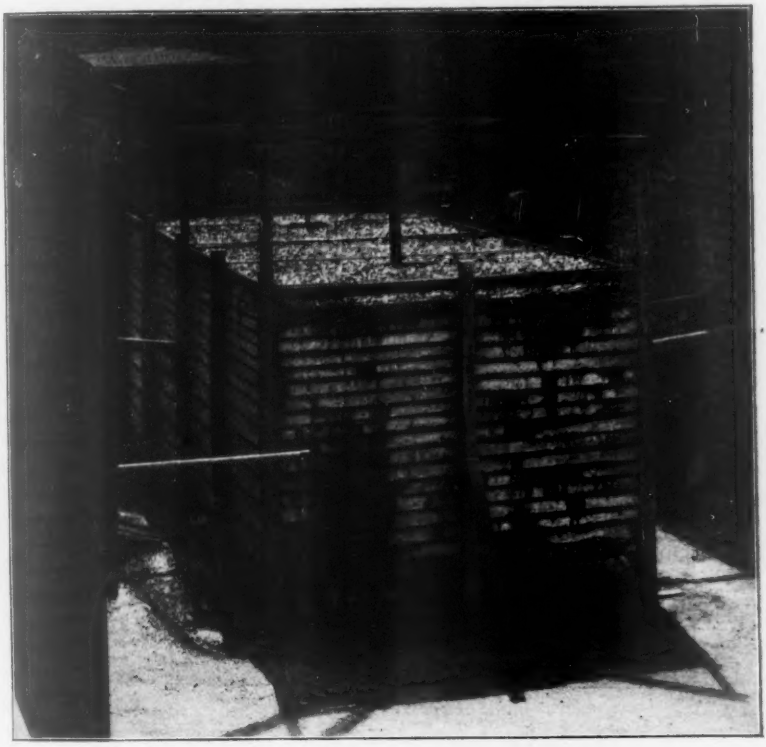


FIG. 3.—VIEW OF EXPERIMENTAL TRICKLING BEDS

brass weir, exactly like that on the distributing tank, regulated the flow on the second trickling bed, filter B.

A general view of the trickling beds is shown in Figure 3. The combined superficial area of both beds was 200 square feet, and the depth 8 feet. A central partition of 2-inch spruce planking, with matched joints, divided the total area into two separate beds, each 10 feet square. Filter A treated crude sewage and filter B septic

effluent. Both beds were filled with crushed stone, granite, and trap, between 1½ and 2 inches in diameter.

The construction of the filters was as follows: For a foundation, 4 × 4 inch spruce beams were buried in the ground, with top surfaces flush. A hemlock floor 1 inch thick was next laid and covered with a layer of 1 to 2 Portland cement mortar, 1 inch thick at the inner corner of the filters near the tank house, and sloping up to a thickness

FIG. 4.—UNDERDRAINAGE SYSTEM OF TRICKLING BEDS

of 3 inches at the opposite side. Four radiating channels in the cement, ½ inch deep, aided the flow to the inner corners, from which the effluent was conducted into the tank house by 1½-inch iron pipes, 8 feet long, with a slope of about 1 foot. The sides of the filter (Fig. 3) were of spruce planks, with ½ to 2-inch openings between them, the lower 18 inches being entirely open. These sides were supported by 4 × 4 inch uprights, braced on all sides and tied at the tops by ½-inch iron rods. On the cement floor two layers of brick were laid in open

courses, as shown in Figure 4, to ensure good underdrainage. On these were 18 inches of bowlders and 65 inches of the main filling material — 1½ to 2-inch crushed stone.

For spraying sewage over the surface of the filter a new method was devised, which we have called the system of gravity distribution. This was described by us a year ago (Winslow and Phelps, 1906 *b*), and has since been adopted by the Massachusetts State Board of Health for its experimental filter at Andover (Clark, 1907). In this system a fine spray is produced, not by throwing the sewage up into the air from a fixed nozzle, but by discharging it downward from an opening in the bottom of a trough on to a concave metal plate, from which it splashes upward. The plan first adopted allowed four such splashing disks for each of our two filters. During this period the arrangement of the system was as follows:

The sewage from the two dosing weirs, in the distributing tank and in the septic tank No. 5, flowed out from the tank house through open wooden troughs, 3 inches in width and 3 inches deep. From these the sewage dropped into similar troughs, which ran from corner to corner of each of the two filters, joining at the centre in the form of a cross. The sewage passed into this cross at its centre, flowed out into the four arms, and dropped through ¾-inch holes to the disk distributors, four to each bed, 100 square feet in area. In each hole was a 3-inch piece of ¾-inch brass tubing, threaded on its upper inch and screwed to a lock nut inside the trough. Any inequality in distribution due to change in the level of the distributing troughs was easily corrected by changing the position of this short tube. Below the troughs the stream of sewage was protected from the wind by a box extending down for 12 inches, and at 15 inches below the trough the stream struck a shallow concave disk, from which it splashed outward. On the filter, as operated during the first year, these disks were 3 inches in diameter, and their concavity had a 6-inch radius. Each was held in place by four ¼-inch brass rods. The general arrangement of this distribution system is shown in Figure 3. It worked with fair success, breaking up the sewage well, and not requiring an excessive amount of attention. Some difficulty was experienced during the winter of 1905–06, but the beds remained in operation. On the coldest days an umbrella of ice surrounded each disk, somewhat limiting the surface distribution; but within this shield the spray worked well.

With disks spaced in this manner, however, there were considerable

intermediate areas of the filter which did not receive sewage, while the portions directly under the disks were operating at excessive rates. During the summer of 1906 pooling occurred on the raw sewage side, and in November of that year we substituted for the four splashing disks

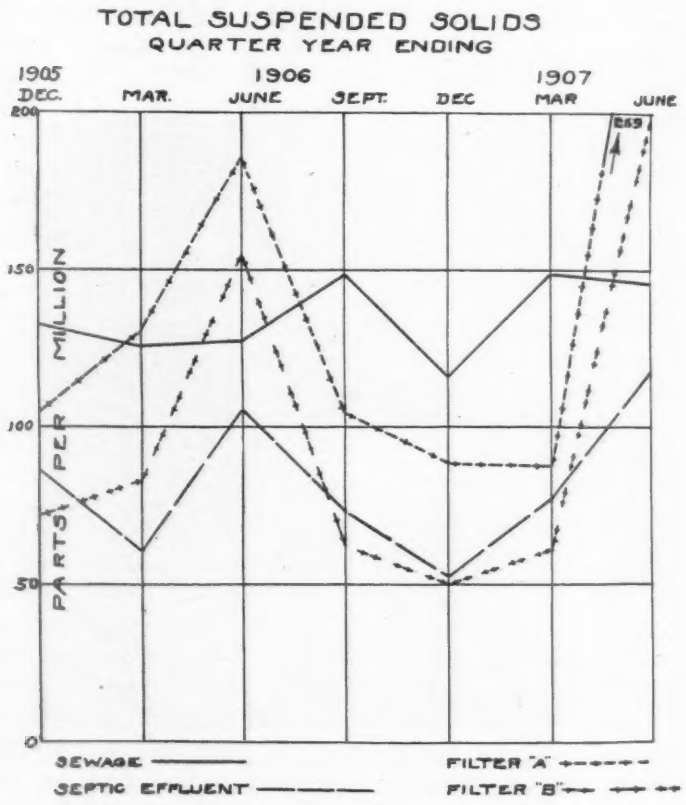


FIG. 5.—QUARTERLY VARIATIONS IN TOTAL SUSPENDED SOLIDS; SEWAGE AND EFFLUENTS

on filter A a single splashing disk of the same type, placed at the centre of the square. This single disk, with four times the discharge upon it, gave a much better distribution over the 10-foot square than its four predecessors. A detailed study of the efficiency of various trickling filter distributors (Winslow, Phelps, Story, and McRae, 1907)

has shown that this type of splashing disk gives more even distribution than any other device, except certain complicated pressure nozzles with small openings. For purposes of comparison we installed on filter B a pressure nozzle of the type used in the early experiments at Columbus, Ohio. This has "a single orifice, $\frac{9}{16}$ inch in diameter, with rounded edges, above which, held by two thin arms, is an inverted

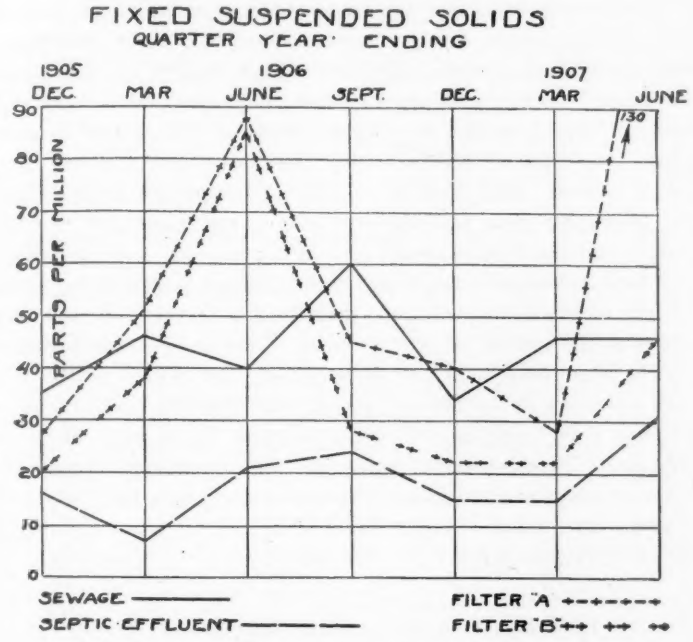


FIG. 6.—QUARTERLY VARIATIONS IN FIXED SUSPENDED SOLIDS; SEWAGE AND EFFLUENTS

90° cone, the axis of the cone coinciding with the axis of the orifice. The jet on leaving the orifice impinges against the cone and is transformed into a thin sheet, spreading out radially and breaking into a shower of fine drops" (Gregory, 1906).

A nozzle with an orifice as large as that of the Columbus sprinkler, when operated with a 4-foot head, as in our experiments, produces an excessive discharge. We therefore placed a dosing chamber between septic tank 5 and filter B, equipped with an automatic, air-locked

siphon, discharging at a head of 4 feet and cutting off at 3 feet. Ball floats operated the air valves, which started and cut off the siphon sharply at the beginning and end of its discharge. In operation, the siphon tank filled in one minute twenty-six seconds, and took one minute ten seconds to empty. It discharged through a 2-inch pipe, which passed into filter B about 6 inches below its surface, rising again at the centre of the bed just above the level of the stones.

The effluent from each filter, as pointed out above, was conducted by the sloping cement floor to the inner corner of each bed, thence flowing through 1½-inch iron pipes to the lower floor of the tank house. Since January, 1906, the effluents from the filters have been sedimented in tanks of special design (see Figs. 2 and 19). Each was a simple inverted cone, with a diameter at the top of 7 feet 2 inches and a height of 4 feet. This form was not so favorable for sedimentation as the Dortmund tank, with sides parallel in the upper part, but was adopted to suit the head room and area at our disposal. At the centre of each tank a vertical tube, 6 inches in diameter, extended to within 1 foot 3½ inches of the bottom. Into the top of this tube the filter effluent was discharged, its velocity being checked by a 3-inch conical cup. The liquid passed out into the tank near the bottom of the tube through openings in its sides. Sludge was removed once a day or once in two days from the bottom of the tank by the valve shown in the diagram. The supernatant liquor rose and overflowed through two 2 × 3 inch collecting troughs. The capacity of each tank was such as to give a two hours' storage period when the filter was running at a rate of 2,000,000 gallons per acre per day.

III. Methods of Sampling and Analysis

All chemical examinations were of composite samples. Portions were collected every three hours, day and night, and at once chloroformed; these were mixed and analyzed at the end of each week. One composite sample of the sewage and of each effluent was analyzed each week for the whole period of investigation.

Turbidity and sediment were observed in each sample by the use of the Jackson turbidimeter recalibrated for coarse material (Phelps, 1905). Total and fixed solids were determined by the Gooch crucible method of Kimberly and Hommon (1906).

Total organic nitrogen values were obtained by a modified Kjeldahl

method, previously described (Phelps, 1905), and during the last year nesslerizations have been made directly by a method devised by Whipple at this laboratory (Whipple, L., 1907).

Free ammonia was read by direct nesslerization against permanent standards. For nitrates the brucine method was used (Farnsteiner,

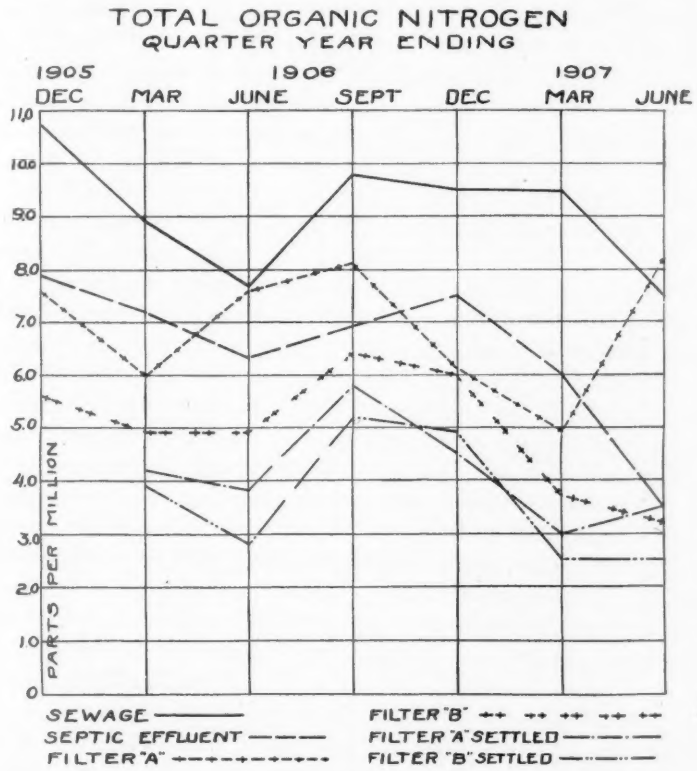


FIG. 7.—QUARTERLY VARIATIONS IN TOTAL ORGANIC NITROGEN; SEWAGE AND EFFLUENTS

1902). "Oxygen consumed" was determined after thirty minutes' heating on the water bath. This determination, and all others not specifically mentioned, were made according to the standard procedure recommended by the Committee of the American Public Health Association (1905).

Experience with the newer processes of sewage treatment has made it clear that the ordinary methods of analysis are insufficient by themselves to furnish all the information necessary with regard to the char-

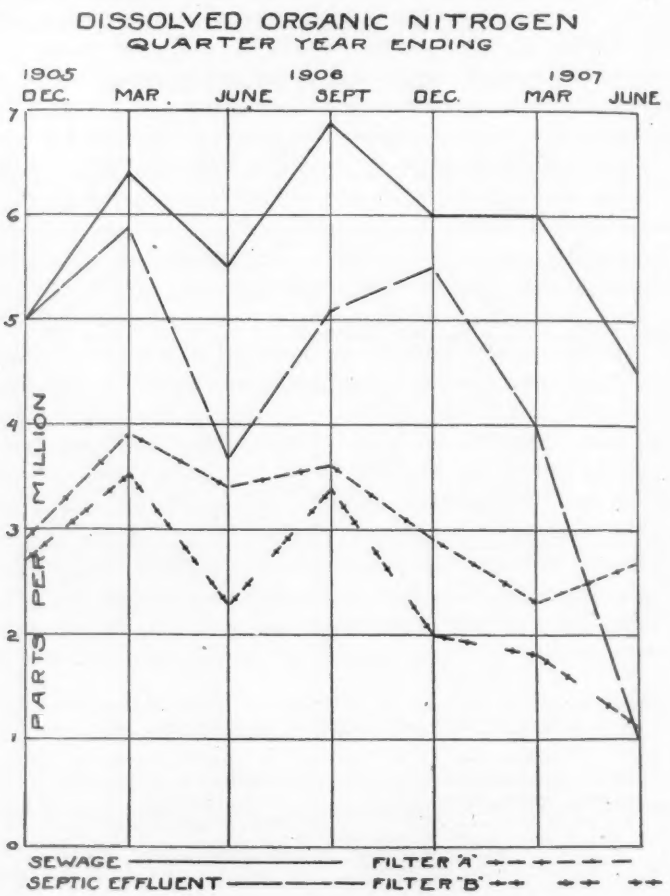


FIG. 8.—QUARTERLY VARIATIONS IN ORGANIC NITROGEN IN SOLUTION; SEWAGE AND EFFLUENTS

acter of a sewage effluent. Our knowledge of sewage chemistry has not yet made it possible to discriminate clearly between putrescible organic matter and those more stable "humus-like" compounds which

do not undergo putrefactive decomposition. With intermittent sand filters, effluents are obtained which contain only a small amount of organic matter of any sort; and the purity of such effluents is easily demonstrable by oxygen consumed and nitrogen determinations. With effluents from contact and trickling filters, on the other hand, the ordinary analytical data do not offer a complete criterion of quality. An effluent may contain a considerable amount of organic nitrogen and give a high value for oxygen consumed, and may yet prove of excellent quality because its organic matter is in a stable form. In such cases it becomes necessary to supplement sanitary analysis by some practical test of keeping quality. Such a test, if its technique is easy, can be made to advantage at more frequent intervals than the more elaborate chemical examinations; and in small plants, where the latter are out of the question, it alone may prove of considerable value.

Although the terms putrescible and non-putrescible stand for quite definite characteristics, yet the separation of effluents of various degrees of purity into these two classes depends to a considerable extent upon the test employed for the purpose, and none of the older tests for stability has proved wholly satisfactory. The "smell test" is inexact, and at the other extreme the determination of oxygen consumed, dissolved oxygen, nitrates, and nitrites is too cumbrous a process for routine work. Furthermore, it does not accurately measure the relation of oxidizable matter to available oxygen, since the oxygen consumed by permanganate bears a variable relation to the organic matter which is oxidizable under natural conditions. The "Manchester test" is somewhat more satisfactory; but this, too, yields abnormal results at times, and only divides effluents into two rough classes, without distinction as to their relative grade.

A new putrescibility test, simple in technique and measuring accurately and delicately the relation between available oxygen and oxidizable matter, has, therefore, been a desideratum. Such a method appears to be at hand in the methylene blue test, first devised by Spitta (1903) for the study of stream pollution, and later more thoroughly worked up by Spitta and Weldert (1906) as a test for sewage effluents. The technique employed is extremely simple. A small portion of an aqueous solution of the dye (in our experiments 1 c.c. of a .1 per cent. solution) is added to the effluent in a glass-stoppered bottle (250 c.c. capacity in our work), and the sample is then incubated either at

20° C. or at 37° C. The blue color of the solution remains practically unchanged during the period of observation until the available oxygen contained is used up and putrefactive conditions arise. At this point the dye is reduced and decolorized. The time required for decolorization is a quantitative measure of the degree of putrescibility of the

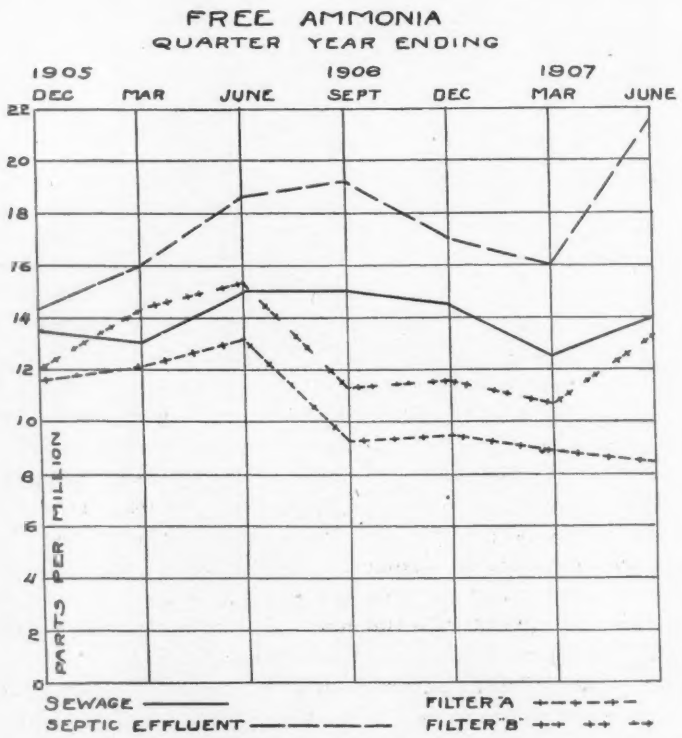


FIG. 9.—QUARTERLY VARIATIONS IN FREE AMMONIA; SEWAGE AND EFFLUENTS

sample, and the retention of the color for a period of four days or more at 20° C., or of two days at 37° C., may be taken as an indication of good stability. The criticism of Johnson, Copeland, and Kimberly (1906), that "substances other than putrescible organic matters, such as sulphide of iron and hydrogen sulphide," discharge the color of methylene blue before the putrescible matters themselves are able to act, does not

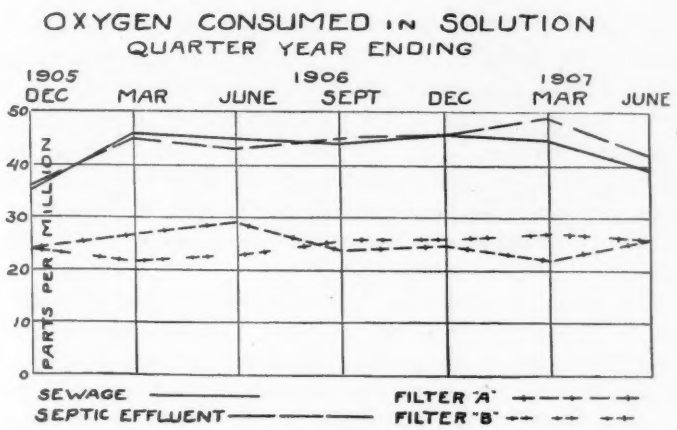


FIG. 10.—QUARTERLY VARIATIONS IN "OXYGEN CONSUMED" IN SOLUTION; SEWAGE AND EFFLUENTS

seem to us well taken, since such substances are present only when the effluent as a whole is in unstable condition.

Spitta and Weldert state that putrefaction occurs from two to four times as fast at 37° as at the ordinary room temperature. We have made a somewhat fuller study of this temperature factor and of some other points in connection with the methylene blue test, which have been reported elsewhere (Phelps and Winslow, 1907). For twenty samples of trickling filter effluents, the decolorization times at 20° and at 37° were determined to the nearest half day, and the ratios of the 20° times to the 37° times are tabulated in Table I. The actual number of days varied from half a day to thirteen days at 37° C.

TABLE I—RATIO OF TIME REQUIRED FOR DECOLORIZATION OF TRICKLING FILTER EFFLUENTS AT 20° TO THAT REQUIRED AT 37° C.

2.5	2.0	1.6	1.6
1.5	2.6	1.0	0.5
2.7	2.0	4.0	2.2
1.8	2.0	2.0	2.3
1.4	1.9	2.4	2.0

With the exception of two very low ratios (.5 and 1) and one high ratio (4), all these figures fall between 1.4 and 2.7, and the average of

all is exactly 2. It may be considered, therefore, that methylene blue samples will generally decolorize at 37° in half the time required at 20°.

It must be remembered in interpreting this table, and all others in which comparative decolorization tests are recorded, that each test must be made in a separate bottle; and since the sampling of sewage is never perfect, there will be variations due to chance differences in the several bottles compared. This is particularly true in work like that later cited in Table III, in which decolorization tests were made in one bottle and analytical data determined on another.

In general, it appears from Table I that results obtained at 20° bear to those obtained at 37° the ratio of 2 to 1. Stable samples are stable at any temperature. In grading putrescible samples, however, it is evidently necessary to select one temperature and to use it for all comparative work. The temperature of the body has the advantage that it gives results more promptly. Any sample which does not decolorize in four days is certainly stable, and a two days' limit would include almost all putrescible effluents. The 20° method, however, from the very fact that it is slower, permits a more delicate measurement of the relative differences between putrescible effluents of different grades. Decolorization here may occur from the first up to the fourteenth day. Slight variations from 20° will not introduce a serious error in the test, and diffuse daylight does not appreciably interfere with it. A series of control experiments made in daylight, in a box at the room temperature (in summer), and in an incubator at 20°, are recorded in Table II, and indicate that the test could be made in an ordinary room with fairly controlled temperature. Experiments made during cold weather in a small frame building heated by a stove showed marked abnormalities, on the other hand, and emphasize the fact that temperature variations cannot be allowed to go too far.

TABLE II — EFFECT OF TEMPERATURE AND LIGHT ON METHYLENE BLUE TEST

Average Time of Decolorization in Days

Week ending	Effluent A.			Effluent B.			Effluent C.		
	Summer temperature.		20° dark.	Summer temperature.		20° dark.	Summer temperature.		20° dark.
	Daylight.	Dark.		Daylight.	Dark.		Daylight.	Dark.	
June 27	1	2	2	11	11	7	2	3	3
July 2	3	3	3	12	12	10	3	3	4
July 9	2	2	2	2	3	2	2	3	3
July 16	2	3	2	9	12	10	13	13	13
July 23	2	3	4	7	8	7	14+	14+	14+
July 30	2	5	6	13	14+	13	12	14+	13
August 6	2	3	3	6	6	6	14+	13	13
August 13	3	5	4	13	13	12	13	13	13
August 20	10	5	5	14+	14+	14+	14+	14+	14+

With regard to the significance of the methylene blue test in relation to the specific chemical changes which go on in putrefaction, Spitta and Weldert have little to say, beyond pointing out that decolorization takes place only after all the available oxygen has been exhausted, which point they illustrate by a single experiment. We have studied the relation between decolorization and chemical processes a little more fully, and the results of the examination of five samples of trickling effluents are shown in Table III.

TABLE III—OXYGEN CHANGES IN PUTRESCIBLE TRICKLING FILTER EFFLUENTS

Decolorization of Methylene Blue Indicated by *

(Parts per Million)

Sample.	Days at 37°.	Dissolved oxygen.	Nitrogen as		Oxygen consumed fifteen minutes cold.
			Nitrates.	Nitrites.	
1	Initial	8.0	3.0	1.0	5.0
	1*	0.0	0.0	0.3	5.0
	2	. .	. .	0.1	. .
2	Initial	10.0	3.0	1.0	4.0
	1	1.0	3.0	1.0	4.0
	2	0.0	0.0	1.0	3.4
	3	0.0	. .	0.1	4.0
	4	. .	. .	0.08	4.0
	5	. .	. .	0.03	3.8
	7	. .	. .	0.0	4.0
	8	. .	. .	. .	4.8
	9	. .	. .	. .	6.3
3	Initial	8.0	3.5	0.5	6.0
	1	1.0	3.0	1.2	4.8
	2	1.2	3.0	1.4	5.7
	3	0.4	3.0	1.0	5.2
	4	0.0	0.0	0.0	5.0
	7*	. .	. .	. .	. .
4. M. B. sample lost	Initial	10.8	4.0	0.3	4.2
	1	1.8	3.0	0.3	4.5
	2	0.2	3.0	0.5	4.4
	3	0.2	3.0	0.1	3.4
	4	0.6	2.5	0.1	2.5
	5	0.0	1.0	0.1	4.3
	6	. .	0.0	0.05	3.6
	7	. .	0.0	0.0	2.7
5	Initial	9.2	3.0	0.6	5.2
	1	1.2	2.5	0.0	5.3
	2*	0.0	0.0	0.0	5.3
	3	0.0	0.0	0.0	5.7
	4	. .	. .	. .	4.6
	5	. .	. .	. .	3.9
	6	. .	. .	. .	6.1
	7	. .	. .	. .	6.9

It is evident that the free dissolved oxygen is absorbed first by the organic compounds present; then the nitrates disappear, and finally the nitrites; and the methylene blue is generally attacked just after the disappearance of the latter. Sometimes, as in samples 2 and 3, there is a considerable delay between the disappearance of nitrites and the decolorization of the methylene blue. This may probably occur when the organic matter and the available oxygen are about evenly balanced, so that after the exhaustion of the oxygen putrefactive changes are set up somewhat slowly. Whenever the methylene blue is decolorized it may be assumed that all oxygen as nitrates or nitrites has disappeared; and, *vice versa*, when the blue color is retained traces of these bodies are generally present. This condition is illustrated in Table IV for trickling filter effluents which did not decolorize after fourteen days at 37°. It will be noticed that these effluents contained a considerable

amount of organic matter as measured by "oxygen consumed," and that in all cases there was a marked reduction in oxygen content during incubation. Nitrites and nitrates remained, however, in all but three cases. This condition may be compared, for contrast, with that of the putrescible effluents in Table III and with four other sets of analyses quoted in Table V.

TABLE IV—Oxygen and Oxidizable Matter in Stable Trickling Filter Effluents

(Parts per Million)

Initial Composition.				After Fourteen Days at 37°.			
Dissolved oxygen.	Nitrogen as		Oxygen consumed fifteen minutes cold.	Dissolved oxygen.	Nitrogen as		Oxygen consumed fifteen minutes cold.
	Nitrites.	Nitrates.			Nitrites.	Nitrates.	
6.8	4.0	5.5	5.6	0.0	0.0	0.0	3.2
2.8	3.0	5.5	8.4	0.3	3.5	1.5	7.6
5.2*	0.0	15.0	4.4	4.0	0.1	15.0	4.4
7.2	5.0	3.0	18.8	0.1	0.4	1.5	8.9
4.4	3.0	3.0	5.2	0.0	0.1	1.5	3.5
7.2	4.0	6.0	16.8	0.1	0.5	5.0	15.8
4.6	3.0	6.0	10.4	0.0	1.5	1.0	12.2
4.4	2.5	5.5	9.6	0.0	0.0	0.0	7.0
4.4	3.0	5.5	8.4	0.2	0.8	1.5	2.0
6.6	1.0	2.0	17.4	0.0	3.0	0.1	2.6
4.2	1.5	3.0	7.2	0.0	1.0	0.0	0.6
5.7	2.5	3.0	8.4	0.0	0.0	0.0	5.2
4.3	3.0	4.0	7.0	0.6	6.0	2.0	7.7

* Sand filter effluent.

TABLE V—Oxygen and Oxidizable Organic Matter in Putrescible Trickling Filter Effluents

(Parts per Million)

Initial Composition				Age, hours at 37°.	After Decolorization.			
Dissolved oxygen.	Nitrogen as		Oxygen consumed fifteen minutes cold.		Dissolved oxygen.	Nitrogen as		Oxygen consumed fifteen minutes cold.
	Nitrites.	Nitrates.				Nitrites.	Nitrates.	
4.3	2.0	3.0	24.4	24	0	0	1.5	25.2
1.1	2.5	3.0	14.0	12	0	0	0.0	14.0
5.8	1.5	5.0	15.6	40	0	0	0.0	16.0
3.8	1.5	5.0	8.8	120	0	0	0.0	2.8

An interesting practical question arises as to the relation of the methylene blue test to the original constitution of the effluent as determined by chemical analysis. If our methods were sufficiently precise we should be able to predict from determinations of organic matter and oxygen just what the result of their interaction will be. The condition of an effluent, as indicated by the relation of oxygen consumed to available oxygen, corresponds, however, only roughly to its putrescibility. Comparing Tables III, IV, and V, a general difference between

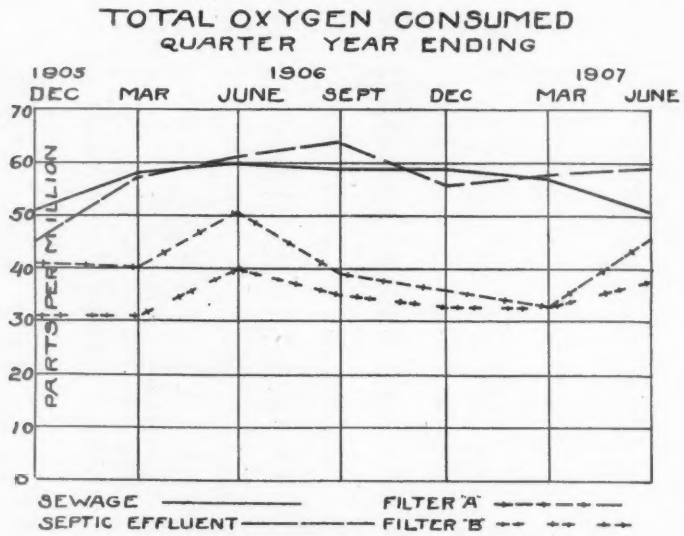


FIG. 11.—QUARTERLY VARIATIONS IN TOTAL "OXYGEN CONSUMED; SEWAGE AND EFFLUENTS

the stable and putrescible samples is apparent, the former, in Table IV, having on the whole a considerably higher ratio of available oxygen to oxygen consumed than the latter, as shown in Tables III and V. There are, however, many samples which contradict this general rule, and we have been unable on any basis of calculation to find a marked and constant difference in analysis between stable and putrescible samples. This has been still more forcibly brought out in our routine experiments. For a considerable period, as will be shown later on, one of our trickling beds gave stable effluents, while those from the other bed were putrefactive. Yet at the same time there were no

significant differences in the nitrogen and oxygen-consumed values of the two effluents. It is evident that certain factors affect the stability of an effluent which are not revealed by the ordinary methods of sanitary chemistry; and since this property of stability is precisely the point of greatest significance in sewage purification, the methylene blue test seems to us of supreme value in judging the work of trickling filters. We have therefore used it since February, 1906, in all our routine work, making daily tests of crude sewage, septic effluent, and trickling effluents before and after sedimentation.

Bacterial samples of sewage and effluents were taken three times a week from October, 1906, to April, 1907, and counts were made on litmus lactose gelatin at 20°. As a presumptive test for *B. coli* the bile medium of Jackson (1906) was used. As in Jackson's work, natural ox-bile was used, with the addition of 1 per cent. lactose; but we incubated our tubes for three days instead of two, which time he first recommended. The reason for this was that a series of sixty preliminary tests gave the results shown in Table VI, which indicated that forty-eight hours is too short a time to allow the development of all the gas-forming organisms present.

TABLE VI—Positive Reactions with Bile Medium at Various Periods

Period of incubation.	Average positive results.	Average per cent. gas.
48 hours	77 per cent.	10
72 hours	92 per cent.	·24
96 hours	95 per cent.	38

For the first three months of regular use, October to December, 1906, the bile test gave good results, yielding positive tests in crude sewage in one-millionth of a cubic centimeter. In January, however, either the number of colon bacilli greatly decreased or the bile obtained was antiseptic. In April *B. coli* could not be isolated by this method from one one-thousandth of a centimeter of sewage.

IV. Composition of Crude Sewage

The sewage of the south Metropolitan district was made slightly weaker in October, 1904, by the diversion of the flow from its more

outlying areas into the new Peddock's Island high level sewer. Comparing the analyses of 1904–05 with those of 1903–04, a diminution of about 10 per cent. in the strength of the sewage was apparent. The analyses made since 1905 are not comparable with preceding ones, since both nitrogen and oxygen-consumed methods were changed at the beginning of the present investigation.

TABLE VII — Composition of Crude Sewage

Quarterly Averages

(Parts per Million)

Year.	Quarter.	Temperature F.	Turbidity.	Sediment.	Suspended Solids.		Organic Nitrogen.		Free ammonia.	Nitrites.	Nitrates.	Oxygen Consumed.		Oxygen dissolved.
					Total.	Fixed.	Total.	Solution.				Total.	Solution.	
1905	4	52	235	120	133	35	10.7	5.0	13.5	0.1	0.2	51	35	3.2
1906	1	43	245	110	125	46	8.9	6.4	13.1	0.0	0.4	58	46	5.6
1906	2	56	285	140	127	40	7.7	5.5	15.0	0.0	0.3	60	45	2.0
1906	3	72	314	160	149	60	9.8	6.9	15.0	0.1	0.0	59	44	0.2
1906	4	54	295	125	116	34	9.5	6.0	14.5	0.0	0.1	59	46	2.5
1907	1	42	320	115	149	46	9.5	6.0	12.5	0.1	0.2	57	45	6.5
1907	2	55	260	80	146	46	7.5	4.5	14.0	0.0	0.0	51	39	3.8
Average	. .	53	279	121	135	44	9.1	5.8	13.9	0.0	0.2	56	43	3.4

The average analysis of the crude sewage for each quarterly period from October, 1905, to June, 1907, is shown in Table VII. Most of the constituents were fairly constant throughout the whole period. The first quarter of the year is characterized by a marked increase of dissolved oxygen and a diminution of free ammonia, due to the inhibition of bacterial decompositions by low temperature. The second quarter of the year is marked by a decrease in organic nitrogen, due to the greater dilution of house sewage at that season with street washings and melted snow. At the same time, the free ammonia value rises with the rising temperature and more active bacterial decomposition. On the whole, the analyses indicate that the sewage used in these experiments was of about average strength for an American sewage. It is weaker than the sewages of many small Massachusetts cities where the proportion of house sewage is large. On the other hand, its organic content is slightly greater than that of the sewage of Columbus (Johnson, 1905). The "oxygen-consumed" value is 56 for Boston against 51 for Colum-

bus; the free ammonia value 13.9 against 11; and the Kjeldahl nitrogen figure 9.1 against 9. Columbus sewage contains only 79 parts of volatile suspended solids, while Boston sewage has 91, but shows 130 parts of fixed suspended solids against 44 parts for Boston.

The average bacterial content of the crude sewage from October, 1906, to April, 1907, inclusive, was 1,200,000 per cubic centimeter as

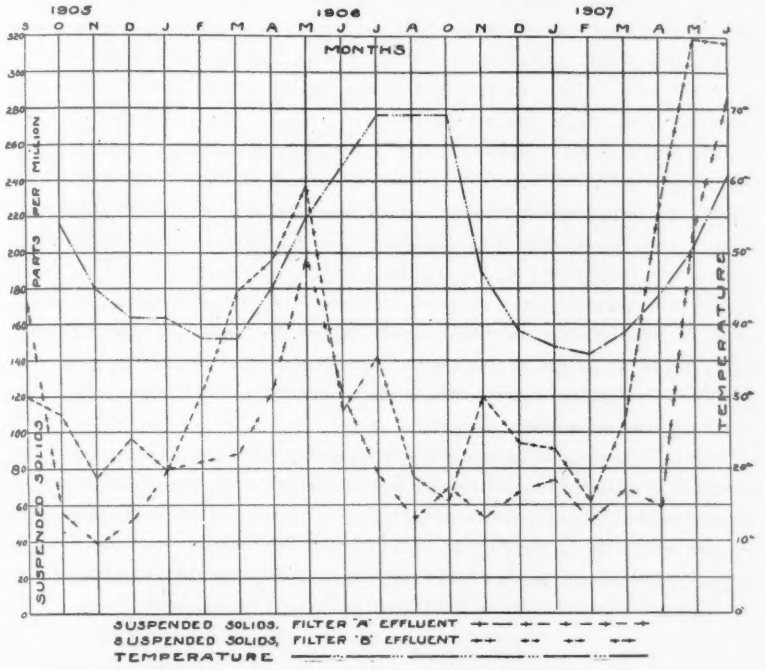


FIG. 12.—MONTHLY VARIATIONS IN TEMPERATURE AND SUSPENDED SOLIDS IN TRICKLING EFFLUENTS

determined by plating on litmus-lactose-gelatin at 20°. Of these, 20 per cent. were acid formers and 8 per cent. liquefiers. The average number of bacteria during the summer months would no doubt have been considerably higher, as shown by previous investigations (Winslow, 1905).

V. RESULTS OF SEPTIC TREATMENT

The septic system used in this investigation consisted, as already stated, of five tanks, each 6 feet long, 4 feet broad, and 3 feet deep.

These were connected by 2.5-inch pipes, and each contained a large baffle projecting from one corner nearly to the opposite corner, as shown in Figure 1. The path of a particle of liquid in each tank was about 10 feet long, and the action of all five tanks approximated that of a single tank 50 feet long and 3 feet wide.

Experiments were begun August 29, 1905, with all five tanks in series, but Nos. 2 and 3 were cut out October 19, 1905, and for one year three tanks alone were used. October 15, 1906, the two extra tanks were again placed in connection with the others. For the first year the total septic period was about seven hours, and for the last eight months it was twelve hours.

On the second day after the tanks were first started a scum formed, which gradually thickened so that after seven days it was sufficiently strong to retain gas bubbles. Masses of black sludge were observed rising to the top of the tank and floating. Conditions remained almost the same during the entire course of the investigation. The scum varied somewhat in amount from time to time, never attaining a thickness of over a quarter of an inch, and often entirely disappearing. Tanks Nos. 1, 4, and 5 operated for twenty months, and Tanks Nos. 2 and 3 for eight months, without any superficial indication of undue accumulation of solids.

There are two distinct processes involved in septic treatment — the removal of suspended solids by sedimentation and the liquefaction of the organic matter by bacterial action. The first of these processes is measured by the character of the effluent discharged, and Table VIII indicates what our septic tanks accomplished from this standpoint.

TABLE VIII — COMPOSITION OF SEPTIC EFFLUENT

Quarterly Averages

(Parts per Million)

Year.	Quarter.	Temperature F.	Turbidity.	Sediment.	Suspended Solids.		Organic Nitrogen.		Free ammonia.	Nitrites.	Nitrates.	Oxygen Consumed.	
					Total.	Fixed.	Total.	Solution.				Total.	Solution.
1905	4	52	175	70	86	16	7.9	5.0	14.3	. .	. .	45	36
1906	1	43	190	80	60	7	7.2	5.9	16.0	. .	. .	57	45
1906	2	58	215	93	105	21	6.3	3.7	18.6	0.1	0.1	61	43
1906	3	73	203	98	72	24	6.9	5.1	19.2	0.0	0.0	64	45
1906	4	53	220	85	52	15	7.5	5.5	17.0	0.0	0.0	56	46
1907	1	44	240	80	77	15	6.0	4.0	16.0	0.0	0.0	58	49
1907	2	55	250	105	118	31	3.5	1.0	21.5	0.0	0.0	59	42
Average	. .	54	213	87	81	18	6.5	4.3	17.5	0.0	0.0	57	44

Comparing the analyses of the septic effluent with those of the crude sewage (Table VII), it appears that the tank system removed 40 per cent. of the total suspended solids and 59 per cent. of the fixed suspended solids. There was a 28 per cent. decrease in the total organic nitrogen and, curiously enough, a 26 per cent. decrease in the organic nitrogen in solution. This latter point shows that the septic tank exercises a certain bacterial purification besides its primary sedimentary action. On the other hand, and, indeed, as a result of the decomposition of organic nitrogen, the tank effluent showed a 26 per cent. increase in free ammonia. "Oxygen-consumed" values were about the same in the effluent as in the crude sewage.

Some interesting points are brought out by a study of the quarterly analyses, which are plotted, for the more important constituents in Figures 5 to 11. Taking the organic matter first, it appears from Figure 7 that the removal of this type of material as a whole does not vary materially from season to season. Figure 8 shows, however, that the soluble organic nitrogen is much more strikingly reduced during the second and third quarters of the year than at other times. At the same season, as appears from Figure 9, the production of free ammonia in the septic tank increases rapidly. These phenomena are both, of course, correlated with the increased bacterial action which follows the setting in of warm weather. The same close relation between

septic action and temperature has been shown by Kinnicutt and Eddy (1902), in their study of the gases formed in a closed septic tank. This point is of much importance in plans for the use of septic tanks under varying climatic conditions, as Fowler has pointed out. In India septic tanks work to perfection, while in Russia they are unsatisfactory (Fowler, 1907).

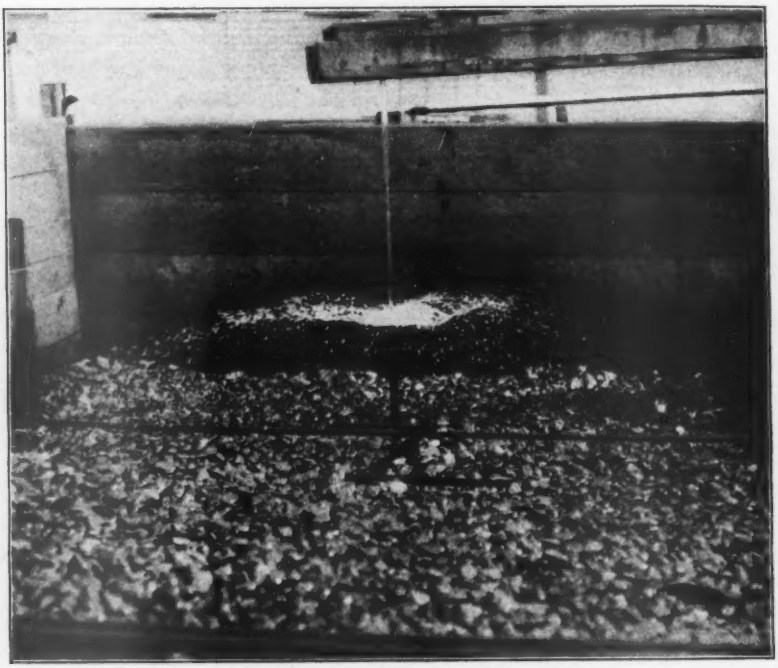


FIG. 13.—VIEW OF GRAVITY DISTRIBUTOR IN OPERATION

Turning to Figures 5 and 6, it appears that the septic tank is least efficient in the removal of suspended solids just at the time when its period of greatest biological activity begins; that is, in the second quarter of the year. This we explain by the active fermentation which manifests itself in the lifting of masses of sludge from the bottom of the tank and the general stirring up of its contents, and naturally leads to the discharge in the effluent of a larger proportion of suspended matter than at times of comparative rest.

Figures 10 and 11, showing the relations for carbonaceous matter, as indicated by the "oxygen-consumed" test, are somewhat surprising from the close parallelism which they indicate between the sewage and the septic effluent. Matter of this class was apparently not appreciably decomposed and scarcely affected by sedimentation. The alternative to this conclusion is to suppose an actual removal of carbonaceous matter, balanced by the production of new reducing bodies. It is difficult to suppose that such a process would yield the uniform results indicated by Figure 11. English septic tanks show, as a rule, a distinct loss of "oxygen consumed" (Winslow and Phelps, 1906*a*).

We believe that differences in results of this sort at different places are to be explained in part, at least, by the different methods in use in determining the oxygen-consumed value. The more vigorous the oxidizing action of the permanganate the more nearly the results approach the true total carbon values. Changes in the nature of the carbonaceous matter, which do not affect its total amount, are quite obscured by analytical procedures like the present standard method, involving a long period (half an hour) of boiling. The less intense English cold methods, on the other hand, give results which are markedly dependent on the nature as well as the amount of the carbonaceous matter. They are therefore extremely valuable in studying those slight chemical changes which accompany sewage purification. It is even possible to detect a difference between the results of the present standard method, involving a half-hour boiling, and the older Massachusetts method of two minutes' boiling, used in this laboratory two years ago. By the latter method our six septic tanks showed an average removal during two years of 14 per cent. of the total "oxygen consumed," as compared with no removal whatever in the present series as determined by the present standard method.

One notable point brought out by these diagrams is the fact that the change from three septic tanks to five, made in October, 1906, did not appreciably alter the character of the effluent. Judged by the analytical results, seven hours' storage is apparently sufficient to effect all the septic changes which will take place in this particular sewage.

The extent to which it accumulates sludge is quite as important a point in the working of a septic tank as the character of its effluent. This point was studied by the method used in our previous investigations. On three occasions — June 30, 1906, when the tanks had run eight months; July 1, 1907, after they had run twenty months;

and August 3, 1907, after they had stood without the addition of fresh sewage for one month — the inlets and outlets of all the tanks were closed and the contents of each tank, including scum and sludge, were thoroughly stirred. Samples of the suspension thus produced were then analyzed in order to gain an idea of the material which had accumulated during the whole period of operation. The results are shown in Table IX. The analyses refer to the total liquid and solid contents

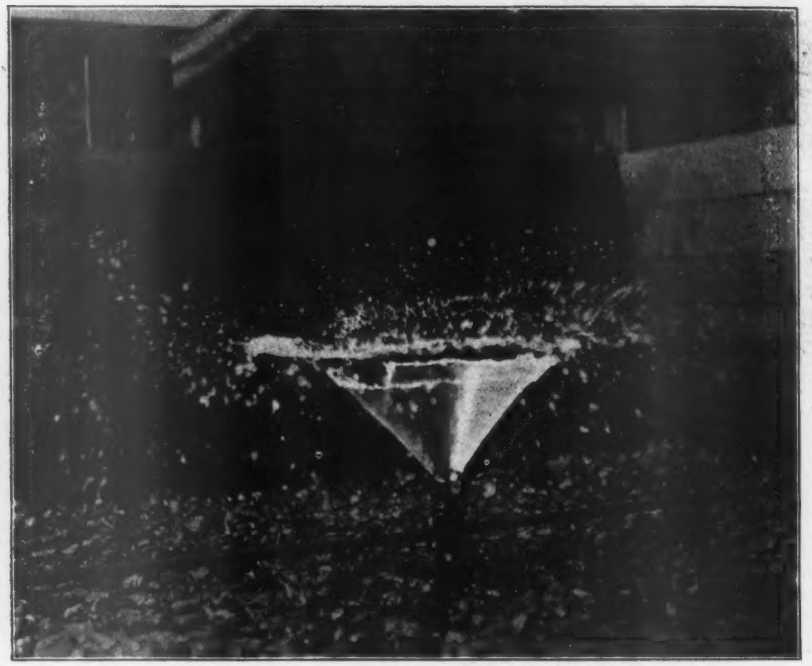


FIG. 14.—VIEW OF COLUMBUS SPRINKLER IN OPERATION

of each tank at the time its operation ceased, a suspension containing about 98 per cent. of water. The sludge was estimated by allowing the mixed tank contents to settle in a cylindrical vessel for twenty-four hours and observing the relation between the thick sediment produced and the clear supernatant liquid. The thickness of the sludge (which as measured by this method includes the scum) was about 4 inches after the first year of operation, and averaged nearly a foot at the end of the investigation.

TABLE IX — ANALYSES OF SEPTIC TANK CONTENTS, INCLUDING SLUDGE AND SCUM

(Parts per Million)

Date.	Tank.	Liquid content.	Depth of sludge.	Solids.		Organic nitrogen.	Oxygen consumed.
				Total.	Volatile.		
		Gallons.	Feet.				
June, 1906	1	518	0.3	7,000	3,900	. .	770
	4	498	0.2	4,400	2,200	. .	520
	5	444	0.3	9,900	4,500	. .	1,200
July, 1907	1	450	0.9	. .	. .	1,000	9,000
	2	468	1.1	. .	. .	1,400	9,900
	3	468	0.8	. .	. .	860	7,300
	4	486	0.9	. .	. .	1,100	9,400
	5	495	0.5	. .	. .	610	5,200
August, 1907	1	450	0.7	25,000	4,000	380	4,900
	2	468	0.5	18,000	3,200	290	3,700
	3	468	1.1	46,000	9,700	590	7,400
	4	486	1.1	38,000	3,000	560	7,000
	5	495	1.2	44,000	7,700	540	7,000

It appears from Table IX that the differences between the individual tanks at a given time were only such as would be expected from sampling errors with a thick organic suspension. The composition of the liquid in the three (or five) tanks was approximately the same at a given time, and the system may therefore be considered as a whole.

Comparing the 1906 analyses with those made at the end of the twenty-one months, it is evident that the amount of fixed solids in the tanks increased considerably during the course of the experiments. The same thing is true of oxygen consumed, and in each case the increase is more than proportional to the time of operation. This is, perhaps, partly due to the fact that during the first year the system was operated with a seven-hour period, and during the second year with a twelve-hour period. Our previous investigations have shown that long storage periods are associated with the undue accumulation of sludge (Winslow and Phelps, 1906 *a*), and similar observations have been made at Lawrence (Massachusetts, 1901).

Over-septic sewage may inhibit the action of the liquefying organisms, or there may occur a secondary precipitation of inorganic reducing

bodies, iron compounds, for example. Too much aging seems, at any rate, to be associated with an increase in fixed solids and in oxygen consumed. The same phenomenon occurs when sludge is stored in a bottle in the laboratory. Table X shows the results of successive analyses of two samples of septic sludge so tested in July, 1906. The mere aging of the septic system as a whole might tend to increase such reactions during the second year. At London and at Leeds a gradual deterioration of septic effluents was noted with the increasing age of the tanks (Winslow and Phelps, 1906*a*).

TABLE X—Septic Sludge before and after Storage

(Parts per Million)

Storage, days.	Fixed solids.	Volatile solids.	Oxygen consumed.
0	33,600	35,880	7,040
2	43,500	36,400	9,960
5	52,560	35,840	10,960
0	30,900	31,400	7,360
2	34,200	26,300	8,340

The effect of a month's rest of the septic tanks is shown by a comparison of the analyses for July and August, 1907. The total amount of sludge did not change materially, but the oxygen-consumed value was slightly reduced and the organic nitrogen dropped more than 50 per cent. Suspended solids were still, however, very high. It is evident that after nearly two years of operation our septic system was approaching the limit of its capacity. With a foot of sludge in the bottom of the tanks, equal to 35 per cent. of the tank capacity, the effluent might soon have been expected to deteriorate. It is probable, therefore, that septic tanks operating with Boston sewage would require emptying once in two or three years.

A somewhat clearer idea of the actual work of the septic tanks may be gained by reducing the analytical data to the actual quantities they represent. During the twenty-one months of the investigation 2,490,000 gallons of sewage passed through the septic system. This volume of sewage carried 2,790 pounds of suspended solids (of which 1,880 pounds were volatile) and 188 pounds of organic nitrogen. The effluent leaving the tanks bore 1,670 pounds of suspended solids (of which 1,300 pounds were volatile) and 134 pounds of organic nitrogen. The septic

system, therefore, removed 1,120 pounds of solid matter (580 pounds volatile and 540 pounds fixed) and fifty-four pounds of organic nitrogen.

TABLE XI — STORAGE AND DECOMPOSITION OF ORGANIC MATTER IN SEPTIC TANKS

Percentages of Sewage Value

	Suspended Solids.		Organic nitrogen.
	Fixed.	Volatile.	
Sewage	100	100	100
Septic effluent	41	69	71
Removed by tank	59	31	29
Stored in tank	62	6	4
Decomposed in tanks	3*	25	25

* Precipitated.

There were left stored in the tanks, after twenty-one months of operation and one month's rest, 675 pounds of solids (of which 109 pounds were volatile) and eight pounds of organic nitrogen. Four hundred and seventy-one pounds of volatile solids and forty-six pounds of organic nitrogen had, therefore, been decomposed in the tanks, while the fixed solids had been increased by twenty-six pounds — additional evidence of the precipitation of inorganic solids previously alluded to. These results are shown in the form of percentages in Table XI, where their relations may be somewhat more easily grasped.

On the whole, it appears that the septic tank will remove nearly two-thirds of the fixed suspended solids from Boston sewage and about one-third of the organic matter, as measured by suspended volatile solids or organic nitrogen. Of the organic matter in the sludge thus removed four-fifths is decomposed. The fixed solids, on the other hand, accumulate to such an extent as to require the cleaning of the tanks once in two or three years. A seven-hour period gives as good an effluent as a twelve-hour one, and probably produces a less accumulation of sludge. All these results harmonize very closely with those obtained in the previous experiments of 1903–05 (Winslow and Phelps, 1906 *a*).

The average bacterial content of the septic effluent for the eight months, October, 1906, to April, 1907, was 750,000, a reduction of

38 per cent. as compared with the crude sewage. The proportion of acid formers and liquefiers was about the same as in the sewage, 16 per cent. of the former and 8 per cent. of the latter. The results of the bile test for *B. coli* were somewhat erratic. In October and November the number of gas formers was apparently increased by passage through the septic tanks; in October 19 per cent. of the tests in one-millionth of a cubic centimeter were positive in the sewage and 56 per cent. were positive in the septic effluent; in November 9 per cent. of the tests were positive in the sewage and 38 per cent. in the septic effluent. From December to April negative results were consistently obtained in one-millionth of a cubic centimeter. The crude sewage showed 19 per cent. of positive results in December, 11 per cent. in January, 12 per cent. in February, and none in March and April.

VI. Results of Trickling Filtration

The general construction of the two trickling filters has been already described and is shown in Figures 1, 2, and 3. Both were 8 feet deep, and the surface of each was a square, approximately 10 feet on a side. Both were filled with 1½ to 2 inch broken stone. Filter A received crude sewage and filter B septic effluent.

The exact area of filter A was 98.47 square feet, or .00226 acre; of filter B, 94.57 square feet, or .00217 acre. The rate on each bed during operation was 200 gallons per hour for twenty-two hours each day, a gross rate of approximately 2,000,000 gallons per acre per day. During the summer months the plant was shut down on Sundays, while in winter it was run continuously to obviate the chilling of the bacteria in the empty bed. In September, 1906, the whole plant was shut down for two weeks. Careful records of operating time show that the filters were operated for 12,450 hours in the ninety-one weeks from October 1, 1905, to July 1, 1907. This means an average operation of 137 hours a week, or 5.7 days. The total amount of sewage applied to each bed was 2,490,000 gallons — an average of 3,900 gallons a day. The net rate of operation was, therefore, 1,730,000 gallons per acre per day for filter A, and 1,800,000 gallons per acre per day for filter B.

Each filter was at first equipped (August 21, 1905) with four gravity distributors — copper disks, 3 inches in diameter, with a 6-inch radius of curvature. Those on the septic side corroded badly, and on November 1 four new disks were substituted on each side to test the durability

of various alloys. Pure aluminum proved as bad as copper, but three alloys — brass, bronze, and a nickel bronze — gave no indications of corrosion. No trouble was experienced in any case on the crude sewage filter.

The winter of 1905–06 was a fairly mild one, as may be seen by reference to Table XII, in which the maximum and minimum temperatures for the three winter months are tabulated from the published data of the United States Weather Bureau. The "normal" December temperature at Boston for different days of the month varies between 27° and 35° F., the normal January temperature between 24° and 31° F., the normal February temperature between 23° and 31° F. Ice first formed on the filters November 11, 1905, and by January 10 all the sprinklers were covered with mantles of ice — tubes about 1 foot in inside diameter, continuous from the box above the sprinkler to the surface of the bed. Inside this mantle all the sewage was distributed, and the areas between the four 1-foot circles were covered with 6 to 8 inches of ice.

In August, 1906, a slight pooling of sewage was observed on the beds, particularly on filter A. On digging into the beds it appeared that just under the four sprinklers the stones were clogged with black sludge. This layer was turned over with a pick to about a foot in depth on filter A, but no material was removed. It was evident, however, that the four sprinkling disks, each operating at a rate of .8 gallon per minute, were not distributing satisfactorily; and this experience illustrates the importance of proper distribution in trickling filters. In the middle of November changes were made in the distributing system as previously described. Filter A was equipped with a single gravity disk just like the four previously used, and filter B was equipped with a pressure nozzle of the Columbus type, and dosed intermittently from a siphon tank. The new distributors in normal operation are shown in Figures 13 and 14.

After this change no difficulty was experienced in securing a satisfactory working of the filters at all times. There was no tendency to surface pooling; analytical results were good, and, as will be seen later, there was no important accumulation of material in the beds. The winter of 1906–07 was much more severe than the previous one, and more severe than the average. Minimum temperatures fell below 5° F. on fifteen different days. On twelve days the maximum temperature was under 20° F.; for five successive days in January and

TABLE XII — MAXIMUM AND MINIMUM DAILY TEMPERATURES FOR WINTER MONTHS

(Degrees Fahrenheit)

United States Weather Bureau

Day.	December, 1905.		January, 1906.		February, 1906.		December, 1906.		January, 1907.		February, 1907.	
	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.
1	33	12	41	32	47	34	47	30	50	39	36	21
2	54	26	33	26	38	6	30	12	30	12	42	30
3	61	39	35	22	18	—1	34	11	40	30	41	17
4	39	28	58	35	42	16	16	4	57	38	20	14
5	35	22	43	37	43	15	36	13	42	35	21	10
6	38	25	41	31	20	3	54	29	45	34	20	8
7	46	35	34	27	23	9	48	4	58	40	24	6
8	55	36	25	16	30	9	14	1	41	37	30	16
9	39	36	28	10	36	28	18	13	43	17	26	14
10	37	18	26	9	37	23	40	18	36	12	39	22
11	32	15	35	15	25	12	32	14	45	35	37	7
12	28	20	54	54	38	24	25	9	38	21	17	2
13	44	20	37	33	40	34	35	25	34	22	27	1
14	36	13	37	25	40	36	34	29	34	26	52	26
15	23	8	35	24	36	13	58	33	29	16	37	28
16	32	20	52	33	33	10	49	35	16	1	42	26
17	37	19	42	32	34	18	37	33	9	—4	39	20
18	51	25	44	31	37	27	36	12	35	9	26	16
19	44	33	38	25	45	32	30	10	42	29	37	14
20	47	36	46	24	53	32	44	24	58	34	36	28
21	51	36	68	46	63	42	45	36	34	18	38	14
22	50	40	63	48	48	34	41	33	34	17	19	4
23	41	37	68	53	38	28	34	15	17	—2	13	—2
24	38	28	60	25	48	31	24	12	8	—7	23	0
25	37	24	26	19	42	31	27	20	16	4	34	11
26	41	26	34	20	48	32	31	20	22	13	22	4
27	51	32	48	29	35	19	43	25	19	10	24	6
28	55	36	46	35	20	9	40	34	28	13	26	2
29	58	38	36	15	. .	. .	47	36	29	12	. .	. .
30	45	37	48	25	. .	. .	41	38	32	11	. .	. .
31	44	35	56	37	. .	. .	53	38	27	6	. .	. .

for four successive days in February the maximum temperature was under 25° F. (see Table XII). Yet ice and snow collected only at the outer edge and corners of the filters, leaving the main part of their surface clear. The condition of the beds at their worst is shown in Figures 15 and 16. The Columbus nozzle kept open a slightly larger circle, but built up a higher wall of ice at the periphery, owing to its intermittent action. It is interesting to note in Figure 16 the extra ice formation at the two points where the knife-edge supports of the spraying nozzle slightly diminish the flow of sewage. Both methods of distribution, however, worked excellently under the severe winter conditions, and the effluents remained well up to standard.

The analyses of the effluents from filters A and B are tabulated by quarters in Tables XIII and XIV. Regular analyses were not begun till October, 1905, but special analyses during the first month of operation showed that the beds rapidly attained a normal activity. Three parts per million of nitrates were found after a week's operation in the effluent of filter A and five parts in the effluent of filter B. The effluents were extremely turbid at first, and after a month still showed more oxygen consumed than the sewage. By the middle of October, after six weeks of operation, turbidity and organic matter decreased, and the beds assumed their normal operation.

TABLE XIII — COMPOSITION OF EFFLUENT FROM FILTER A

Quarterly Averages

(Parts per Million)

Year.	Quarter.	Temperature F.	Turbidity.	Sediment.	Suspended Solids.		Organic Nitrogen.		Free ammonia.	Nitrites.	Nitrates.	Oxygen Consumed.		Oxygen dissolved.
					Total.	Fixed.	Total.	Solution.				Total.	Solution.	
1905	4	47	155	85	104	27	7.6	2.9	11.6	1.0	3.8	41	24	7.6
1906	1	39	170	110	130	51	6.0	3.9	12.1	0.5	4.0	40	27	9.3
1906	2	53	300	205	186	88	7.6	3.4	13.2	1.8	4.3	51	29	4.7
1906	3	69	183	108	104	45	8.1	3.6	9.3	2.5	3.9	30	24	4.9
1906	4	52	185	155	88	40	6.1	2.9	9.5	0.6	4.5	36	25	7.7
1907	1	39	210	115	87	28	4.9	2.3	8.9	0.3	5.4	33	22	11.2
1907	2	51	270	170	269	130	8.2	2.7	8.5	0.7	5.2	46	26	10.2
Average	. .	50	200	136	138	58	7.1	3.1	10.4	1.1	4.4	41	25	7.9

TABLE XIV — COMPOSITION OF EFFLUENT FROM FILTER B

Quarterly Averages

(Parts per Million)

Year.	Quarter.	Temperature F.	Turbidity.	Sediment.	Suspended Solids.		Organic Nitrogen.		Free ammonia.	Nitrites.	Nitrates.	Oxygen Consumed.		Oxygen dissolved.
					Total.	Fixed.	Total.	Solution.				Total.	Solution.	
1905	4	45	90	45	72	20	5.6	2.7	12.0	0.9	4.1	31	24	8.0
1906	1	39	130	60	83	38	4.9	3.5	14.3	0.1	4.3	31	22	9.3
1906	2	62	215	140	155	85	4.9	2.3	15.3	1.2	4.4	40	23	4.4
1906	3	60	128	66	62	28	6.4	3.4	11.3	3.3	4.5	35	26	5.4
1906	4	52	120	65	50	22	6.0	2.0	11.5	1.2	4.6	33	26	7.6
1907	1	37	145	65	61	22	3.7	1.8	10.7	0.7	5.0	33	27	10.2
1907	2	52	200	105	198	46	3.2	1.1	13.3	1.0	5.7	38	26	8.2
Average	. .	51	147	78	96	37	5.8	2.4	12.6	1.2	4.7	34	25	7.6

From the Tables VII, VIII, XIII, and XIV and from Figures 5 and 6 it appears that the total amount of suspended solids discharged by each filter was slightly in excess of that received by it. An average value of 135 parts per million in the crude sewage was increased to 138 in filter A, and a value of 81 parts in the septic effluent was increased to 96 parts in filter B. A very interesting seasonal curve is indicated, however. The amount of solid material was less in the effluent than in the applied sewage except in the second quarter of the year. In some quarters, filter A effected a 40 per cent. reduction in suspended solids. In the second quarter of each year, there was an enormous increase of suspended solids in the effluent to a point in excess of the amount in the applied sewage. This means, of course, that the suspended solids of the sewage are ordinarily held on the bacterial films which cover the stones, while during the second quarter the accumulated material is washed out again into the effluent. We suspected at first that spring rains might account for this phenomenon, but a more careful study showed that the increase of solids in the effluent did not correspond to heavy rainfall, and it appeared from calculation that this factor could not be of great importance. Two inches of rain falling in an hour would double the rate on a 2,000,000-gallon per acre filter, but such a storm rarely occurs in the latitude of Boston. Monthly values for suspended solids and temperature,

which have been tabulated in Table XV, show, on the other hand, a suggestive correlation.

TABLE XV — SUSPENDED SOLIDS AND TEMPERATURE OF TRICKLING EFFLUENTS

Month.	FILTER A.		FILTER B.	
	Temperature F.	Solids.	Temperature F.	Solids.
September, 1905	. .	120	. .	173
October	55	110	54	56
November	46	75	45	39
December	41	97	41	52
January, 1906	40	79	41	80
February	39	122	38	. .
March	37	178	38	88
April	46	195	45	124
May	55	237	55	197
June	61	112	62	121
July	69	142	69	76
August	70	75	69	52
September	. .	. .	. .	. .
October	69	62	69	70
November	48	120	47	53
December	40	94	39	68
January, 1907	39	91	37	74
February	37	62	36	51
March	40	107	39	69
April	44	223	44	59
May	51	319	51	213
June	60	316	61	288

The figures in Table XV are tabulated in graphic form in Figure 12. Both filter effluents show a progressive decrease of solid material from May onward till the early spring, when a sudden increase occurs. The trickling filter evidently has its own definite yearly life cycle, and upon this, rather than upon the applied solids, do the solids in the effluent depend. It seems probable that the bacterial films upon the stones absorb or otherwise hold the solid material which reaches them until by this process of accretion and their own multiplication the mass becomes heavy enough to break away With Boston sewage a year's supply of solids can thus be stored; but

the bacterial multiplication set up, when warm weather begins, serves to upset the equilibrium of the bed, and the solids collected during the preceding ten months are discharged. It will be noted, however, by reference to Figure 12, that solids began to increase in A effluent before the onset of warm weather. In each year its rise preceded that of B by two months. This bed received a considerably larger amount of suspended solids than filter B, and it seems probable that the mere accumulation of material began to cause the detachment of zoöglœa before the spring increase in growth occurred. There is at any rate abundant evidence here that the trickling bed automatically frees itself from suspended solids after accumulation has taken place to a certain extent. This phenomenon will militate strongly against permanent clogging of the trickling bed.

In this connection the nature of the suspended matter is also of significance. In filter A the volatile suspended solids were reduced, on the average, from 91 parts to 80 parts, while fixed suspended solids were increased from 44 parts to 58; in filter B volatile suspended solids fell from 63 parts to 59, while fixed suspended solids rose from 18 parts to 37. The larger increase of fixed suspended solids in the septic side is probably due in part to the precipitation of iron sulphide, a deposit of which was later found on the bottom of the bed. In filter A, however, there is no evidence of such a reaction, and the figures seem to indicate a real conversion of organic matter into some insoluble mineral form. It is apparent to the eye that the suspended matter in the effluent of a trickling filter is quite different from that which goes on at the top. It is in much larger particles, as may be seen by the eye, and it settles much more easily. It is for this reason that the turbidity of both effluents was considerably reduced (200 for filter A against 279 in the sewage, and 147 for filter B against 213 in the septic effluent). Microscopic examination by the Sedgwick-Rafter method (Whipple, 1905), carried out under our direction by Mr. H. S. Spaulding, showed that the finely divided particles of suspended matter, of a size less than five standard units, were reduced from 300,000 per cubic centimeter in crude sewage to 28,000 in trickling effluent, while the larger particles, and particularly the macroscopic particles, were increased in numbers. In appearance the material in the trickling effluent is structureless and somewhat flocculent, resembling the amorphous matter so frequently found in water analysis. In its formation the original suspended matter applied to the filter has evidently been

thoroughly worked over. It is somewhat surprising, in view of these facts, that the sum of the suspended matter applied and discharged should tally so nearly.

In organic content both effluents show a marked reduction. The purification per cent., as measured for each of the principal constituents, is shown in Table XVI. The results are remarkably close, with the exception of the total "oxygen-consumed" value for the septic side, which exception may be accounted for by the precipitation of iron compounds already alluded to. In all other cases there was a reduction of about 25 per cent. in total organic matter and 40 per cent. in organic matter in solution.

TABLE XVI — PURIFICATION EFFECTED BY TRICKLING BEDS

Percentages

	Organic Nitrogen.		Free ammonia.	Oxygen Consumed.	
	Total.	In solution.		Total.	In solution.
Filter A	22	47	25	27	42
Filter B	23	44	28	40	43

Figures 7 to 11 show that in general the organic matter in the effluent does not exhibit any marked seasonal variations. There is one striking exception, however, to this rule. From Figure 11 it appears that the total "oxygen-consumed" value rose inordinately in the second quarter of each year. This is evidently correlated with the increased discharge of suspended solids at the same time, and it is clear, since no corresponding increase in nitrogen occurred, that the organic matter which then appeared in the effluent was chiefly carbonaceous. This fact strengthens the possibility that the material discharged from the trickling bed is largely bacterial zoöglœa.

Two other points only demand special mention, the dissolved oxygen in the effluents and their content of mineral nitrogen. Dissolved oxygen was at all times present in both effluents in considerable amounts. It was highest in the first quarter of each year, when bacterial decompositions were checked by the cold, and it was distinctly higher during the second year than the first, owing to the better system of distribution. The values for nitrites and nitrates are plotted in Figure 17. Nitrites were at a maximum in both effluents in the autumn of 1906; since the 1907 curve stops at July 1 it is uncer-

tain whether the same phenomena would have been repeated in that year. It is apparent, however, that the process of nitrite formation is markedly favored by high temperatures. The curve for nitrates, on the other hand, shows a pretty steady increase from the beginning to the end of the experiments, and indicates a progressive improvement in nitrifying power. Taking the sum of the organic and ammoniacal nitrogen in applied liquid and effluent, in comparison with the sum of the nitrates and nitrites, it appears that filter A received 23 parts of unoxidized nitrogen (organic and ammoniacal) and discharged 17.5 parts of unoxidized and 5.5 parts of oxidized nitrogen, nitrates, and nitrites. Filter B received 24 parts of unoxidized nitrogen and discharged 17.6 parts of unoxidized and 5.9 parts of oxidized nitrogen. There is, therefore, no evidence of appreciable storage or loss of nitrogen in filter A, and filter B shows a difference of only half a part. Table XVI shows that the per cent. purification effected by filters A and B was approximately equal as regards organic matter. Since the liquid applied to filter B had undergone preliminary treatment in the septic tank its effluent was, of course, actually superior to that of filter A. It contained only 96 parts of suspended solids against 138 parts for filter A, 5 parts of organic nitrogen against 7.1 parts, and 34 parts of oxygen consumed against 41 parts. Its free ammonia content was, however, higher, making the sum of the ammonia and organic nitrogen practically the same in both cases (17.6 and 17.5). The only significant difference between the effluents lay, therefore, in the fact that filter A discharged more suspended solids, both fixed and volatile, than filter B.

These results of chemical analysis are of considerable theoretical interest as throwing light on the processes which go on in the trickling bed; but, as we have pointed out already, they do not adequately measure the practical value of the purification effected. Neither the analyses of the effluents nor the figures for purification per cent. would by themselves suggest that our beds were doing satisfactory work. The methylene blue test, on the other hand, showed that the effluents of both filters were for the most part stable, and it is this test which furnishes the true criterion of their quality.

The methylene blue test was made on each effluent daily from February, 1906, to the end of the experiments, and the results are plotted in Figures 18-*A* and 18-*B*. The black blocks indicate the periods of decolorization by days up to fourteen days, the maximum time of observation.

During the cold months of February and March, 1906, results were notably irregular for both effluents. The sample collected on one day might prove stable, while that of the next would decolorize in two or three days.

With the beginning of warm weather, which favors harmful putrefactive changes, both before and during the process of filtration, both

FIG. 15.—VIEW OF GRAVITY DISTRIBUTOR UNDER SEVERE WINTER CONDITIONS

effluents further deteriorated. Filter B recovered about the end of May, and throughout the summer its effluent was generally stable. Filter A remained in poor condition until September, and was uncertain in its action for two months longer. The contrast between these beds brings out very clearly the great delicacy of the methylene blue method of testing effluents. The analyses for the third quarter of 1906 in Tables XIII and XIV show, indeed, a slight superiority for

filter B, but it is far too slight to lead to the conclusion that at this time one of the filters was practically a success and the other practically a failure.

With the installation of the new sprinklers in November, 1906, a decided change was manifest. After the middle of December, by which time the filter organism had become adjusted to its new conditions, both effluents were almost constantly stable. Occasionally, particularly during the winter months, and with filter A, a putrescible effluent was obtained, but this was rare. From December 15, 1906, to June 28, 1907, 156 samples of each effluent were examined by the methylene blue test. On the crude sewage side 127 samples were stable for fourteen days, nineteen more were stable for over four days, and ten only became decolorized in four days or less at 20°. The effluent of filter B showed 129 samples stable for fourteen days, sixteen more stable for more than four days, and eleven which were decolorized in four days or less. In other words, on 93 per cent. of the days both effluents were of sufficiently good quality to retain free oxygen for over four days.

Three conditions appear mainly responsible for imperfect operation when it did occur. In the first place, excessively low temperatures evidently impair the activity of the purifying organisms. The break in the curve for both filters on February 28, 1906 (see Fig. 18-*A*), was coincident with a fall from 19° to 9° F. The bad results obtained during the first week of December, 1906, accompanied minimum temperatures of 4° to 9° F. (Fig. 18-*B*). After the new distributing apparatus was in good working order, however, this effect of cold weather was only slight. Thus the severe weather of January 16 to 18, January 23 to 25, February 11 to 13, and February 22 to 24, 1907 (see Table XII), shows only slight effects in Figure 18-*B*.

The second factor affecting the stability of the effluents was the spring discharge of suspended solids. This phenomenon in April, 1906, evidently caused the bad break in the quality of the effluents manifest at that time and indicated in Figure 18-*A*. The interesting point in this connection is, however, that the much larger amount of suspended solids washed out in the second quarter of 1907 (see Fig. 5) produced no corresponding increase in putrescibility; that is, with proper distribution the solids discharged are so well oxidized or otherwise rendered stable that they do not interfere with the stability of the effluent.

The third factor which affects the character of the effluent

unfavorably is irregularity in the operation of the filter. In Figure 18-*A* the sample taken after a day's rest (the Monday sample) appears again and again the worst of the week, and during the second year the only serious interference with the work of filter B followed the three days' rest of May 18 to 21. This action was always most marked in cold weather. Whether it is due to the injury of the bacteria in the filter by changed conditions or to the detachment of

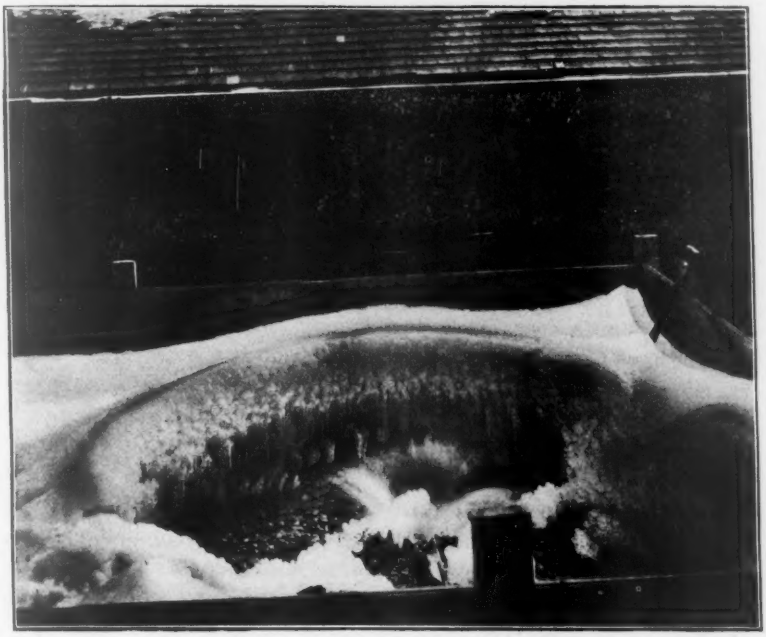


FIG. 16.—VIEW OF COLUMBUS SPRINKLER UNDER SEVERE WINTER CONDITIONS

dried zoöglœa is uncertain. It is clear, however, that resting the filter is detrimental to the effluent, and the results for the second quarter of 1907 show that the necessary removal of accumulated material can be accomplished in a natural way without such unfortunate results. We are therefore led to conclude that extended periods of rest for the recuperation of the bed and drying up of the accumulated organic material are not only unnecessary, but actually detrimental, and that the operation of a trickling filter should be made as constant and uniform as possible.

TABLE XVII—STABILITY OF TRICKLING FILTER EFFLUENTS

Percentage of Samples Decolorized at Each Specified Period

"A" EFFLUENT.										Total samples.
Days		0-2	2-4	4-6	6-8	8-10	10-12	12-14	14+	
Year.	Quarter.									
1906	1	40.5	18.9	2.7	5.4	8.1	0.0	0.0	24.4	37
1906	2	42.6	26.0	20.6	2.7	2.7	2.7	0.0	2.7	73
1906	3	23.7	38.9	15.3	5.1	6.8	0.0	0.0	10.2	59
1906	4 *a*	2.4	9.5	14.3	4.8	9.5	7.1	2.4	50.0	42
1906	4 *b*	2.9	11.4	2.9	8.6	11.4	2.9	8.6	51.3	35
1907	1	2.7	4.1	6.7	2.7	2.7	4.1	8.1	68.9	74
1907	2	4.4	2.9	1.5	0.0	1.5	2.9	1.5	85.3	68

"B" EFFLUENT.										Total samples.
Days		0-2	2-4	4-6	6-8	8-10	10-12	12-14	14+	
Year.	Quarter.									
1906	1	38.8	16.7	5.5	8.4	8.4	5.5	2.8	13.9	36
1906	2	16.9	22.6	26.7	2.8	9.8	1.4	1.4	18.4	71
1906	3	11.9	15.3	10.2	5.1	0.0	0.0	3.4	54.1	59
1906	4 *a*	2.3	0.0	0.0	0.0	4.5	2.3	2.3	88.6	44
1906	4 *b*	14.6	20.4	14.6	11.6	2.8	5.8	5.8	24.4	34
1907	1	4.0	4.0	0.0	2.7	1.3	0.0	4.0	84.0	75
1907	2	5.8	0.0	5.8	5.8	1.4	0.0	0.0	81.2	69

The results of the methylene blue test for each quarter are indicated in Table XVII, samples being divided by their decolorization periods into eight classes, those which decolorized inside of two days, between two and four days, between four and six days, etc., the last class including those which were still stable after fourteen days. The fourth quarter of 1906 is divided so as to differentiate the samples collected before and after the change in the distribution system.

The table shows in each case poor results with the old system of distributors. Filter B treating septic effluent was much better than filter A, however, and showed a steady improvement during this period. When the Columbus sprinkler was installed on filter B a serious temporary derangement followed; but by January, 1907, the filter had become adjusted to the new conditions, and for the last six months yielded effluents, 93 per cent. of which were stable for four days and over 80 per cent. stable for fourteen days. The substitution of a single

gravity distributor instead of four on filter A was followed by a steady improvement. Ninety-three per cent. of the samples of A effluent have been stable for four days since January, 1907, and the percentage stable for fourteen days rose from nearly 70 per cent. in the first quarter of the year to 85 per cent. in the second.

Bacterial examinations showed an average of 200,000 bacteria per cubic centimeter in the effluent of filter A and 180,000 in the effluent of filter B. The figures correspond to removals of 83 per cent. and 76 per cent., respectively, figured on the applied liquid. The proportion of acid formers and liquefiers was about the same as in the crude sewage.

At the close of the twenty-one months of experimentation the trickling filters were dug out and carefully examined. Samples of the filtering material were taken at various points; the accumulation between the stones was carefully removed by washing with a brush and the resulting liquor analyzed. In both filters the top of the beds was quite clean. In filter A there was an accumulation of fine material extending from 3 inches down for about a foot just under the four old distributors. This deposit covered four circles, each about a foot and a half in diameter, and was, of course, chargeable to the earlier imperfect process of distribution. In this layer, where the maximum deposit occurred, the extraneous matter amounted to .3 pound per cubic foot, of which 44 per cent. was organic. The remainder of filter A showed no visible accumulation of foreign material, and the underdrains and concrete floor of the bed were as clean as when they were laid. In filter B there was a slight deposit from 6 inches to 18 inches below the surface, amounting to .07 pound per cubic foot, while the remainder of the bed was clean. On the floor of B, however, there was a deposit of sludge half an inch thick, amounting to 4 cubic feet in all (1,720 cubic feet, or 64 cubic yards, per acre). This sludge contained 22 per cent. of water and 1.4 per cent. volatile solids. Qualitative tests showed it to consist of a mixture of finely divided silica with a considerable proportion of sulphide of iron.

From the stone analyses at various depths we have calculated in Table XVIII the total amounts of material stored in each filter and the corresponding values per million gallons. The excess of nitrogen on the septic side is suggestive.

TABLE XVIII—STORAGE OF MATERIAL IN TRICKLING FILTERS

	Pounds per Filter.			Pounds per Million Gallons.		
	Fixed solids.	Volatile solids.	Organic nitrogen.	Fixed solids.	Volatile solids.	Organic nitrogen.
Filter A. Crude sewage	36.4	5.5	0.6	14.6	2.2	0.2
Filter B. Septic sewage	5.3	6.6	2.7	2.1	2.6	1.1

In addition to these deposits in the beds the sludge on the bottom of filter B amounted to 697 pounds, or 280 pounds of dry solids, per million gallons. Such material could easily be removed by washing with a hose in a filter with a properly constructed underdrainage system.

VII. Sedimentation of Trickling Effluents

The effluents from the trickling filter, although stable, contain so much suspended matter as to be unsightly, and under many circumstances further treatment for the removal of suspended solids would be desirable. As shown at many of the English plants and at Columbus (Johnson, 1905), such a removal may be accomplished by simple sedimentation, since the suspended particles in the effluent are sufficiently large to settle out with ease. Since January, 1906, the effluents from filters A and B have been treated in this manner. The tanks used for sedimentation have been described above, and their general construction is indicated in Figures 1 and 2. One of the tanks, photographed before it was put into place, is shown in Figure 19.

The tanks were of conical form, with a central vertical funnel which received the inflowing liquid at the top and discharged it into the body of the tank near its bottom. The supernatant liquid was carried off from the top by two surface channels, and sludge was drawn off by a valve at the bottom. The capacity of each tank was a little under 350 gallons, equivalent to a sedimentation of an hour and three-quarters. Experiments made by Mr. R. R. Patch in a thesis study showed that liquid dyes colored the whole surface of the tank in seven and a half minutes. On the other hand, when a culture of *B. prodigiosus* was poured into the central tube, plates made every five minutes from the outflowing liquid first showed the germ after one hour and gave maximum numbers after an hour and a half.

The character of the effluent from the sedimentation tanks is indicated by the quarterly average analyses in Tables XIX and XX.

TABLE XIX — COMPOSITION OF FILTER A EFFLUENT AFTER SEDIMENTATION

Quarterly Averages

(Parts per Million)

Year.	Quarter.	Turbidity.	Sediment.	Suspended Solids.		Organic Nitrogen.		Free ammonia.	Nitrites.	Nitrates.	Oxygen Consumed.	
				Total.	Fixed.	Total.	Solution.				Total.	Solution.
1906	1	115	45	116	56	4.2	3.9	13.0	0.6	3.9	31	26
1906	2	165	85	53	15	3.8	2.3	13.8	2.1	4.3	36	31
1906	3	100	45	55	20	5.8	4.2	6.3	2.5	4.0	29	25
1906	4	90	50	30	12	4.5	3.0	9.0	0.7	4.5	30	27
1907	1	160	85	50	11	3.0	2.0	9.5	0.5	5.5	29	26
1907	2	135	60	83	29	3.5	2.0	9.5	0.9	5.4	31	25
Average	..	128	62	65	24	4.1	2.9	10.2	1.2	4.6	31	27

TABLE XX — COMPOSITION OF FILTER B EFFLUENT AFTER SEDIMENTATION

Quarterly Averages

(Parts per Million)

Year.	Quarter.	Turbidity.	Sediment.	Suspended Solids.		Organic Nitrogen.		Free ammonia.	Nitrites.	Nitrates.	Oxygen Consumed.	
				Total.	Fixed.	Total.	Solution.				Total.	Solution.
1906	1	90	30	40	14	3.9	3.2	15.0	0.1	4.4	26	23
1906	2	135	70	63	27	2.8	2.3	14.9	1.2	4.5	30	23
1906	3	76	45	31	11	5.2	4.0	10.7	2.9	4.6	30	28
1906	4	80	35	23	7	4.9	3.5	11.5	1.2	4.4	29	26
1907	1	115	50	34	12	2.5	1.5	10.5	0.8	5.0	31	28
1907	2	140	75	110	37	2.5	1.5	13.0	1.3	6.1	29	27
Average	..	106	51	50	18	3.6	2.7	12.6	1.3	4.8	29	26

A comparison of the general averages in Tables XIX and XX with the average for the unsettled effluents in Tables XIII and XIV indicates the efficiency of the sedimentation process, and this efficiency has been expressed in purification per cent. in Table XXI.

TABLE XXI — PERCENTAGE PURIFICATION EFFECTED BY SEDIMENTATION

	Suspended Solids.		Organic Nitrogen.		Free ammonia.	Oxygen Consumed.	
	Total.	Fixed.	Suspended.	Soluble.		Suspended.	Soluble.
A effluent	53	59	70	6	2	75	8*
B effluent	48	51	58	13*	0	66	4*

(* = increase.)

Sedimentation for two hours in the conical tanks used in these experiments removed about half the suspended solids present. The removal of suspended nitrogen and carbonaceous matter (oxygen consumed) was in each case greater than the removal of suspended matter in general. Coupled with the increase in soluble nitrogen and carbonaceous matter, this makes it clear that a certain amount of liquefying action went on at the bottom of the tanks. Nitrites and nitrates were unaffected, however, as may be seen by reference to Figure 17. It will be noticed that the per cent. purification effected was always less in the case of the septic effluent. This is, no doubt, because the liquid before treatment contained less gross material to remove. The finer portions of suspended matter naturally settle out less readily.

No important seasonal variations were noted in the action of the sedimentation tanks, except in the case of the organic nitrogen. This constituent, as plotted in Figure 7, was less reduced in the autumn months than at any other time, while at this period (the third quarter of 1906) the soluble organic nitrogen was largely increased. Its value rose from 3.6 to 4.2 in the case of A, and from 3.4 to 4 in the case of B effluent. This was, of course, due to the increased septic action going on in the tanks during the warm season. Bacterial results also indicated the existence of organic activity in the sedimentation tanks. The average number of bacteria in the settled effluent of filter B for the seven months — October, 1906, to April, 1907 — was 260,000 — an increase of 44 per cent. on the effluent entering the sedimentation tank.

The best measure of the efficiency of sedimentation is the methylene blue test, and the decolorization periods for the settled effluents are indicated by the unshaded blocks in Figures 18-*A* and 18-*B*. At times during the winter and spring of 1906 even the settled effluent was putrescible. In general, however, most of the effluents which putrefied in their

original state were rendered stable when their solids were reduced by sedimentation. The months of July and August, 1906, furnish a good instance of this. During the whole period forty-nine samples were examined. Of the unsettled effluents forty-five from filter A and twenty from filter B became decolorized inside of fourteen days, but of the corresponding sedimented samples only ten from filter A and nine from filter B became decolorized. After the new distribution system was in working order twenty-nine samples from A and twenty-seven samples from B decolorized in less than fourteen days. Of the corresponding settled samples thirteen from filter A and seventeen from filter B became decolorized.

It must be remembered in interpreting these results that our tanks were not of the best form for securing efficient sedimentation. Their shape was conditioned by the head room at our disposal, and a deeper tank, more of the usual Dortmund shape, would give better results. Furthermore, the pipe for removing sludge from our tanks was so small that sludge could not be drawn off rapidly, and considerable stirring up of the contents of the tank was the result. With tanks of proper design, planned for a full two-hour flow and with proper arrangements for sludge removal, results would undoubtedly be better.

Against the advantages to be gained by the sedimentation of the trickling effluent must be set the new problem of sludge disposal which is introduced. Since September, 1906, this problem has been studied by careful measurement and analysis of the material removed from the sedimentation tanks, and the general results are brought together in Table XXII. The analyses are grouped by four periods, in which the method of removing sludge from the tanks differed as follows: From September to December 3, 1906, and from April 9 to June 29, 1907, twenty-five gallons of sludge and water were drawn from each tank every other day by the valve for removing sludge shown in Figure 2. The three samples for each week were chloroformed, mixed, and analyzed. Reference to Table XXII shows that by this method the liquid removed from the tank was considerable in amount and contained only 10 to 20 per cent. of true sludge. If sludge is removed as often as this it cannot be obtained in very compact form in tanks of such a construction as ours. From December 4, 1906, to January 14, 1907, sludge was removed once a week, the tanks being drawn down to a point 2 feet from the bottom. In this way a more concentrated liquid was obtained. During the third

period (January 14 to April 8, 1907) no samples were taken. The sludge was allowed to accumulate, which produced no harmful results in the cold weather; and at the end of the period the tank was drawn

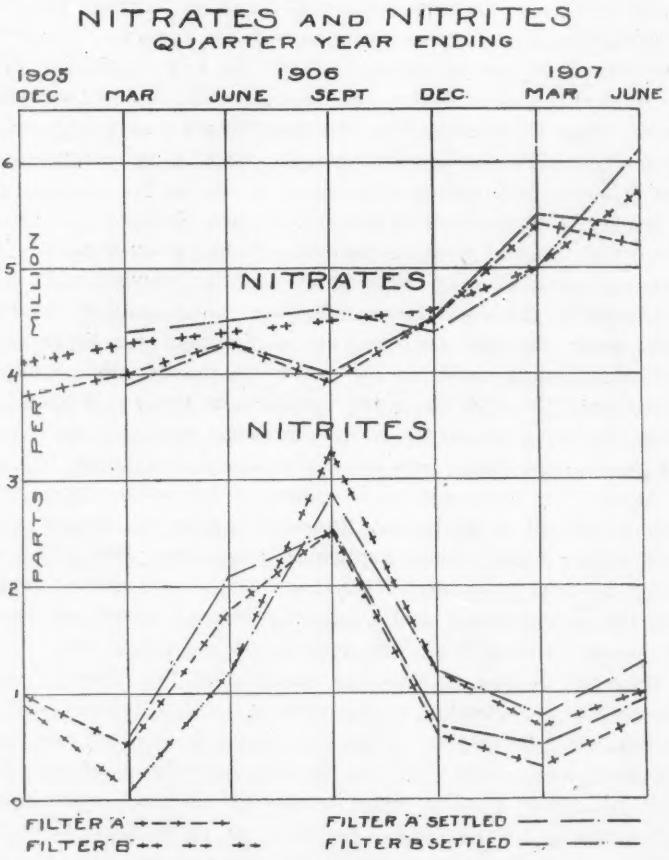


FIG. 17.—QUARTERLY VARIATIONS IN NITROGEN AS NITRATES AND NITRITES; CRUDE AND SETTLED EFFLUENTS

down to a depth of 1 foot 9 inches, and the remaining liquid removed and analyzed.

The cubic yards of wet sludge removed in each period varied for A effluent from .40 to 1.29 and for B effluent from .18 to .73. Per mil-

FILTER B
DAYS
Rated 12 hours
Rated 12 hours
Rated 12 hours
Rated 12 hours
Rated 24 hours
Rated 24 hours
Rated 24 hours
Rated 12 hours
Rated 12 hours
FILTER A
DAYS
Rated 12 hours
Rated 12 hours
Rated 12 hours
Rated 12 hours
Rated 24 hours
Rated 24 hours
Rated 24 hours
Rated 12 hours
Rated 12 hours
FEBRUARY
MARCH

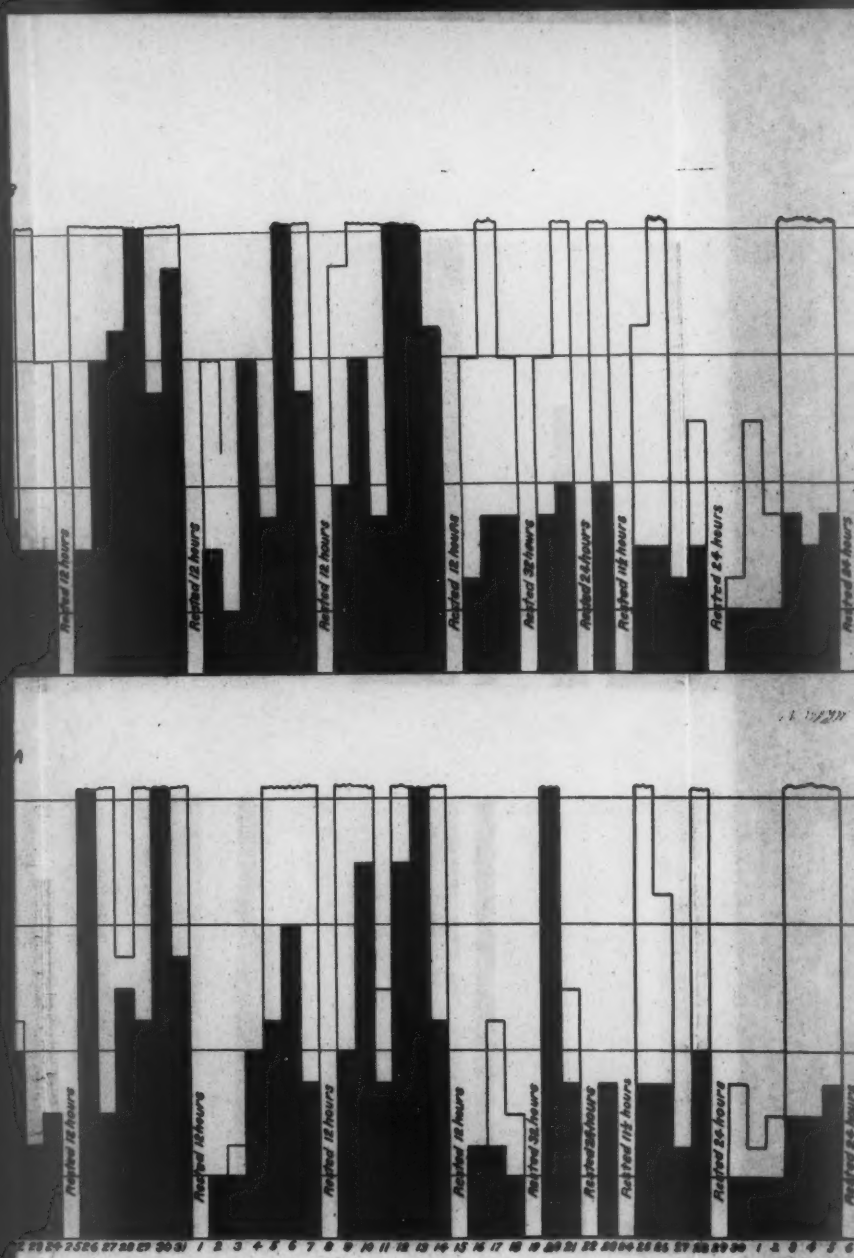
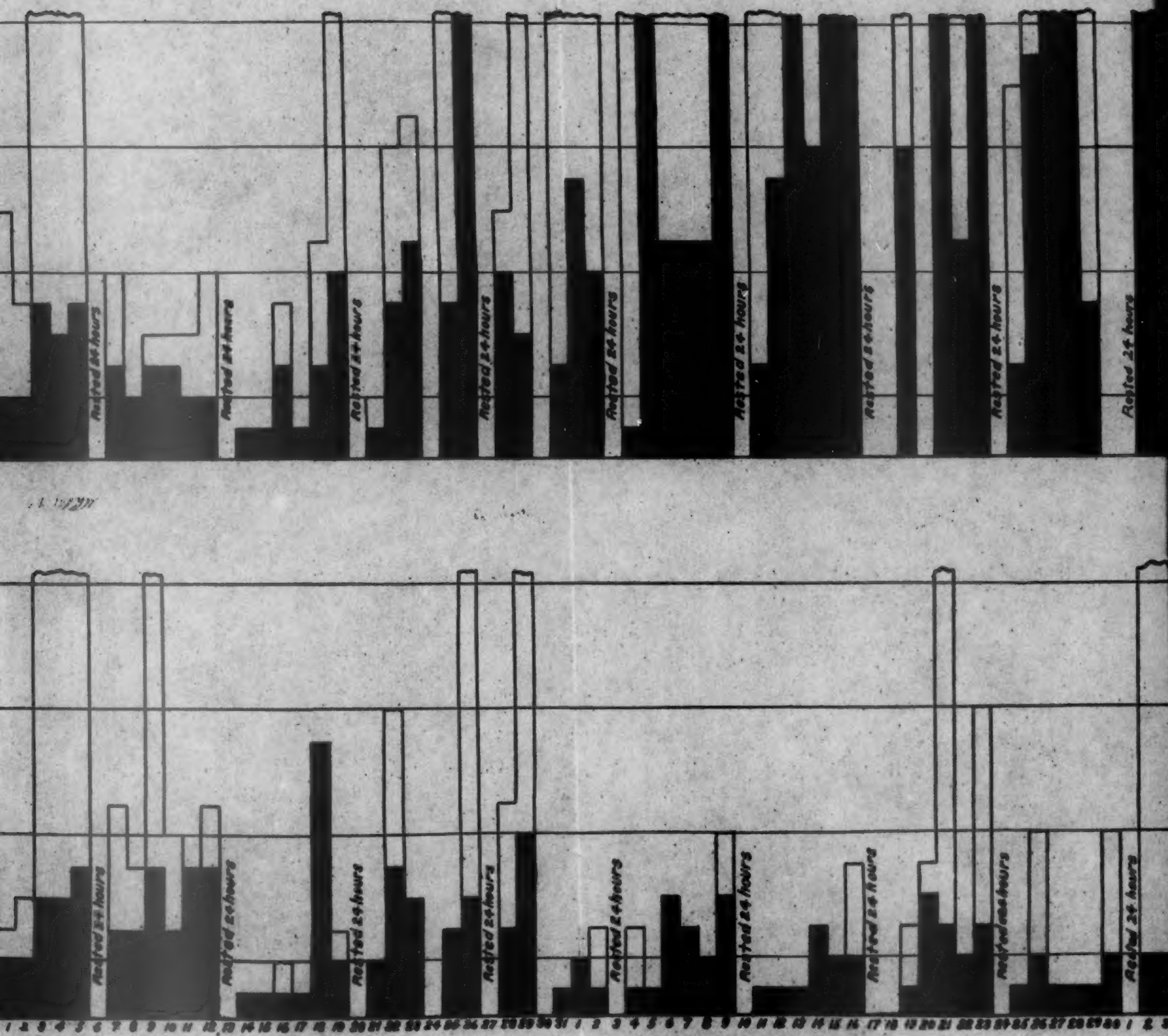


FIG. 18–*A*.—DAILY RECORD

Abscissæ = successive dates.
Ordinates = number of days for which sam

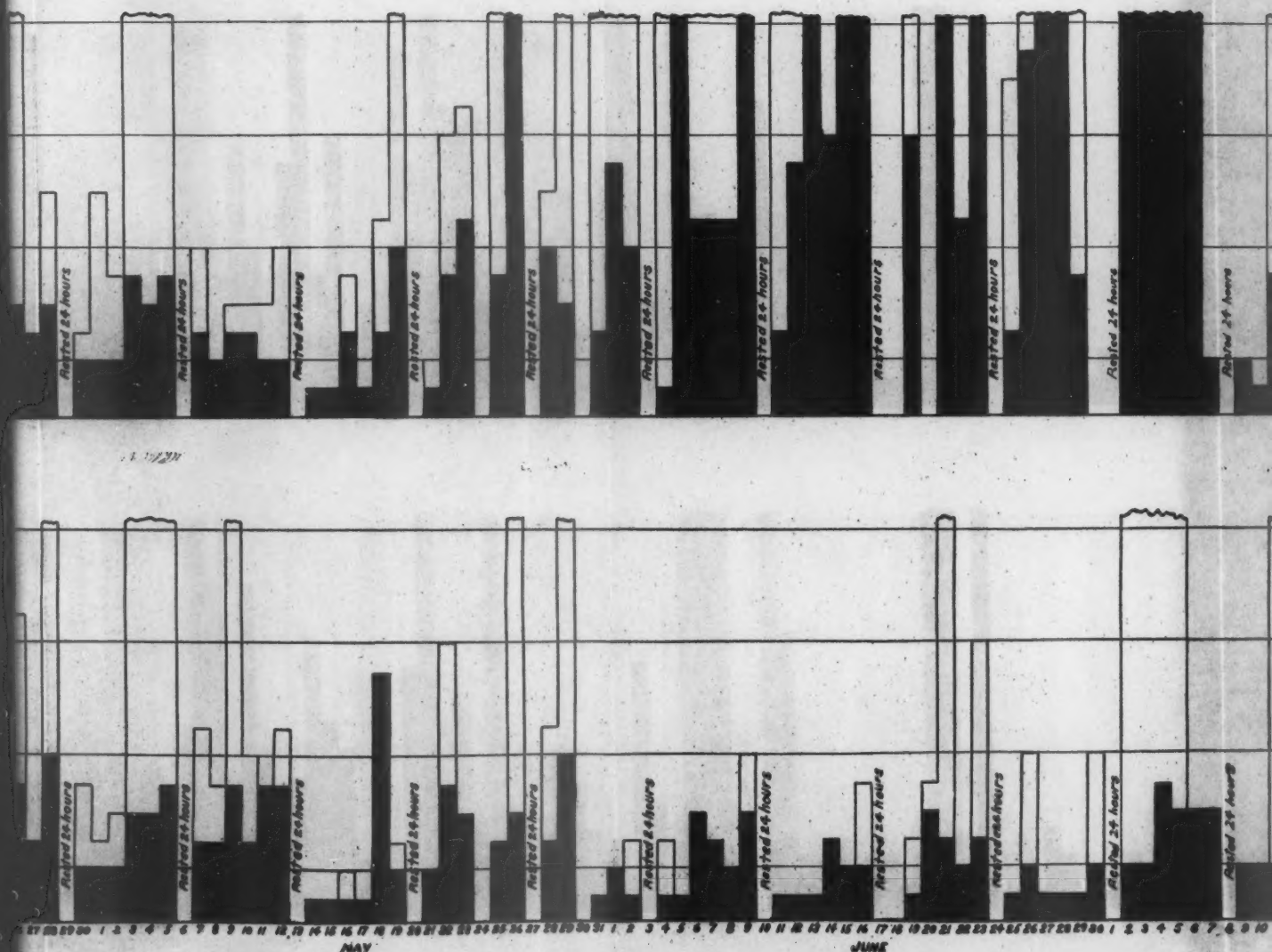


ILY RECORD OF STABILITY OF SETTLED AND UNSETTLED TRICKLING EFFLUENTS. FEBRUARY—AUGUST, 1906

for which sample remained stable at 20°.

Upper line = Filter B effluent.
Lower line = Filter A effluent.

Outline blocks = settled effluents.
Solid blocks = unsettled effluents.

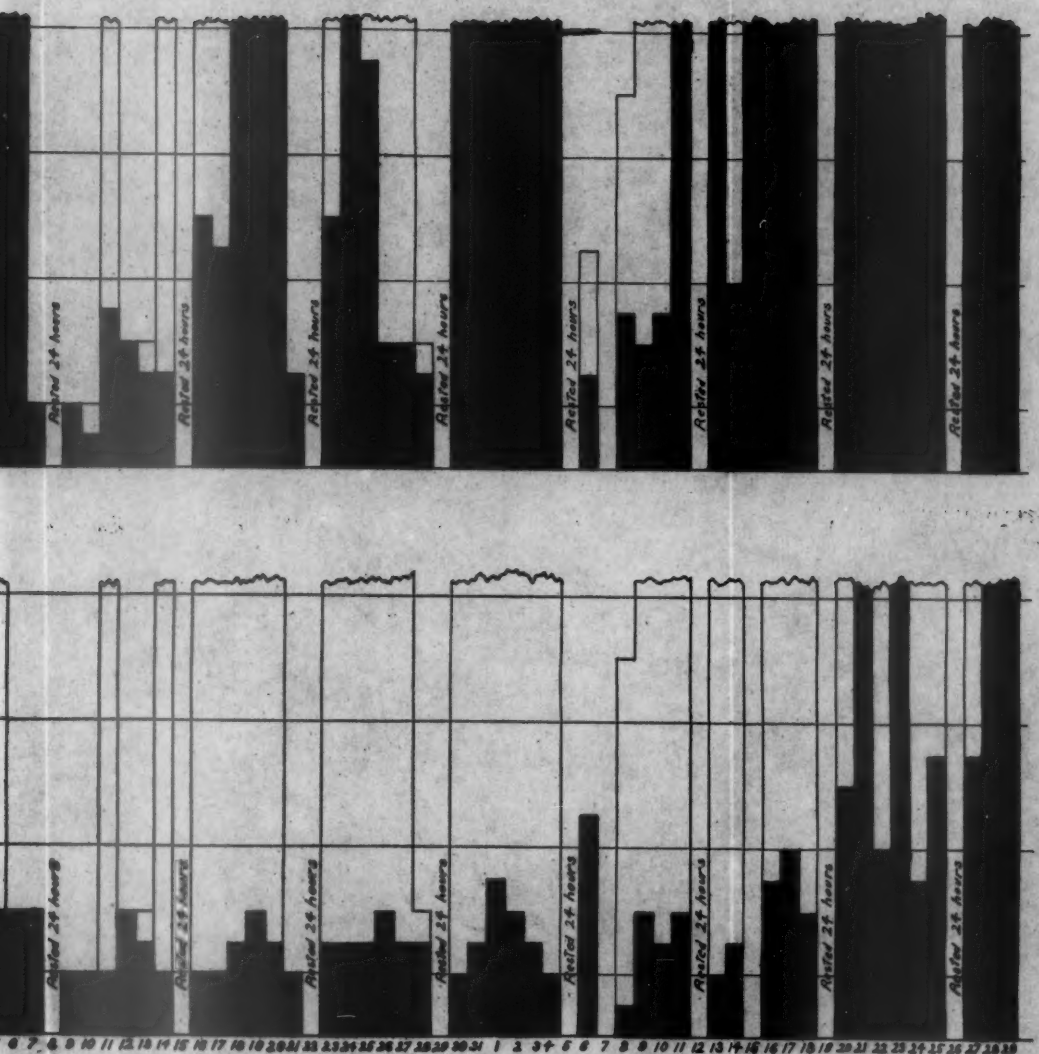


-A.—Daily Record of Stability of Settled and Unsettled Trickling Effluents. February—August, 1906

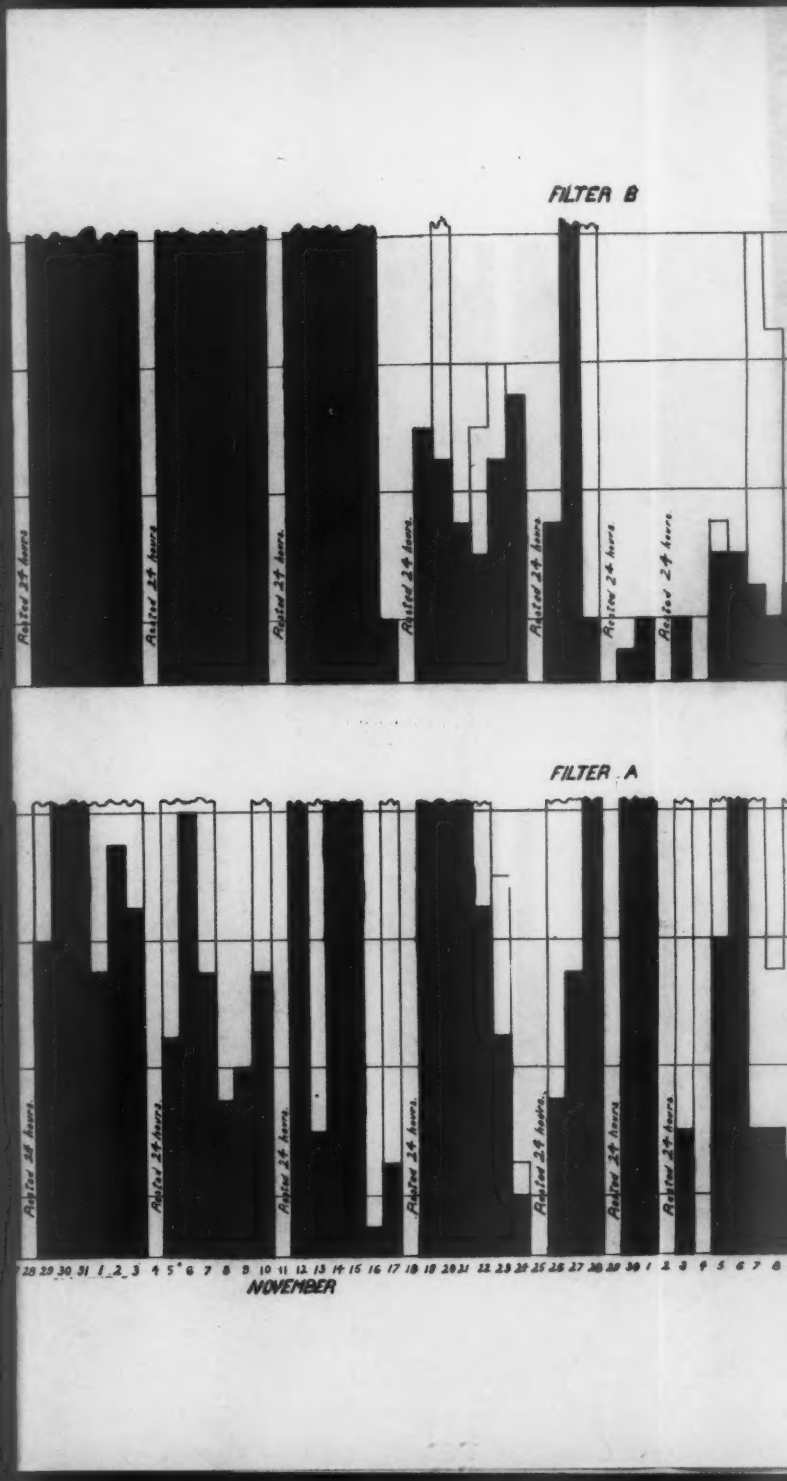
ssive dates.
ber of days for which sample remained stable at 20°.

Upper line = Filter B effluent.
Lower line = Filter A effluent.

Outline blocks = settled effluents.
Solid blocks = unsettled effluents.


Rainfall 24 hours
Rainfall 24 hours
Rainfall 24 hours
Rainfall 24 hours
Rainfall 24 hours
Rainfall 24 hours
Rainfall 24 hours
Rainfall 24 hours
Rainfall 24 hours
Rainfall 24 hours
Rainfall 24 hours
Rainfall 24 hours
6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29
JULY
AUGUST

DAYS
SEPTEMBER
OCTOBER
Rested 24 hours.
Rested 24 hours.
Rested 24 hours.
Rested 24 hours.
Rested 24 hours.
Rested 24 hours.
Rested 24 hours.
Rested 24 hours.
Rested 24 hours.
Rested 24 hours.
Rested 24 hours.
Rested 24 hours.


FILTER B
Raised 24 hours.
Raised 24 hours.
Raised 24 hours.
Raised 24 hours.
Raised 24 hours.
Raised 24 hours.
Raised 24 hours.
FILTER A
Raised 24 hours.
Raised 24 hours.
Raised 24 hours.
Raised 24 hours.
Raised 24 hours.
Raised 24 hours.
Raised 24 hours.
28 29 30 31 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 1 2 3 4 5 6 7 8
NOVEMBER

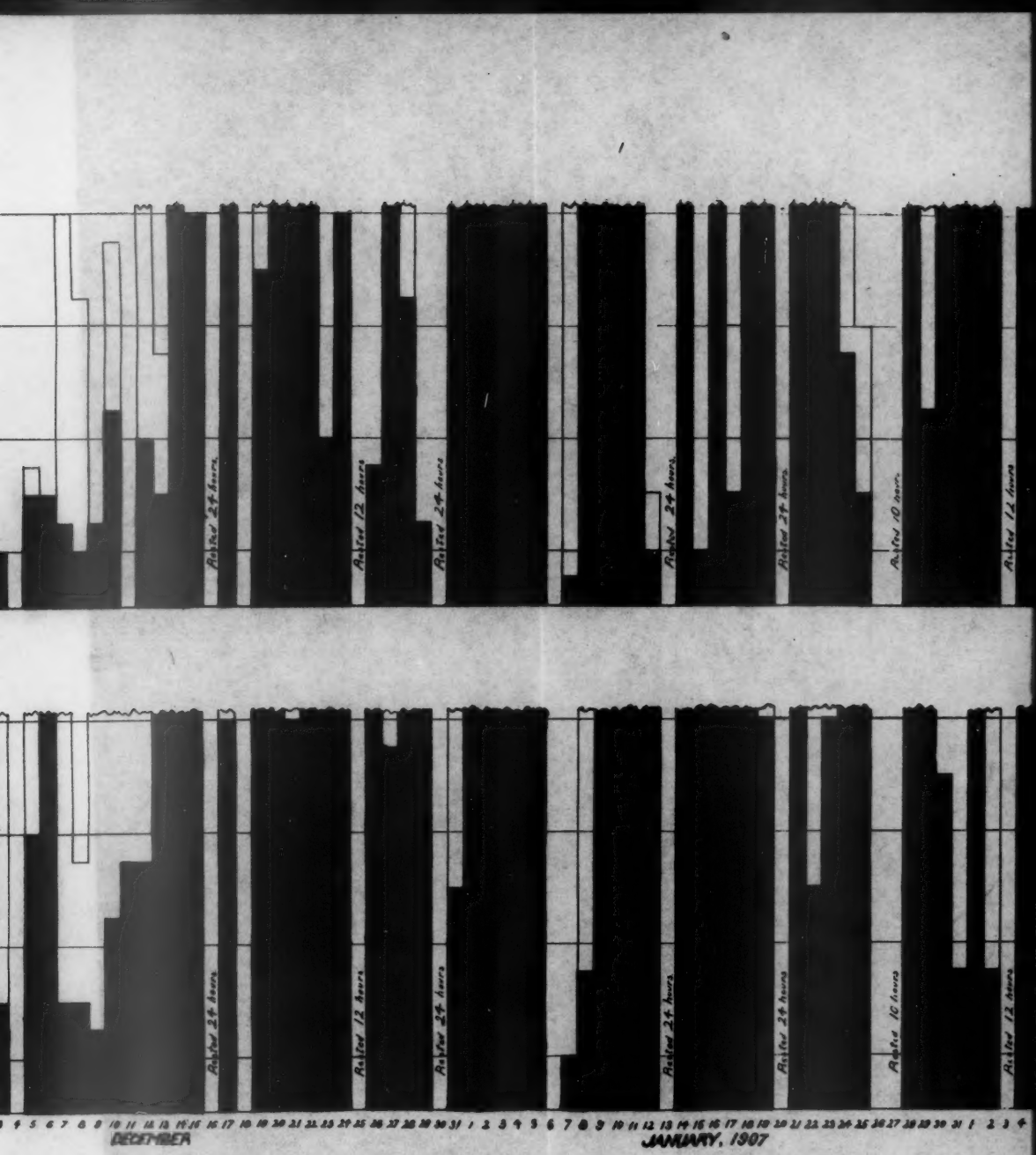


FIG. 18–*B*.— DAILY RECORD OF STABILITY OF SETTLE

Abscissæ = successive dates.
Ordinates = number of days for which sample remained stable at 20°.

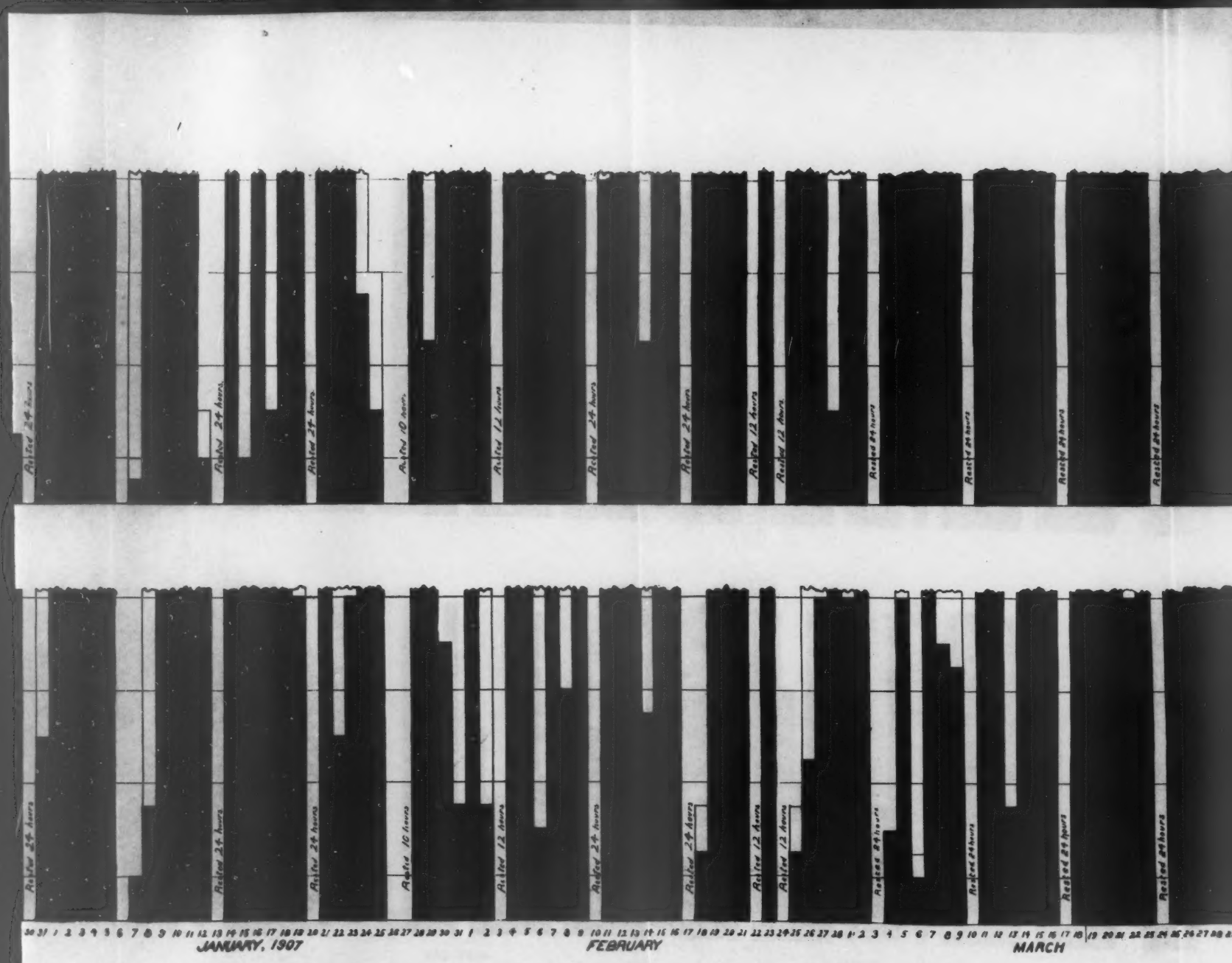


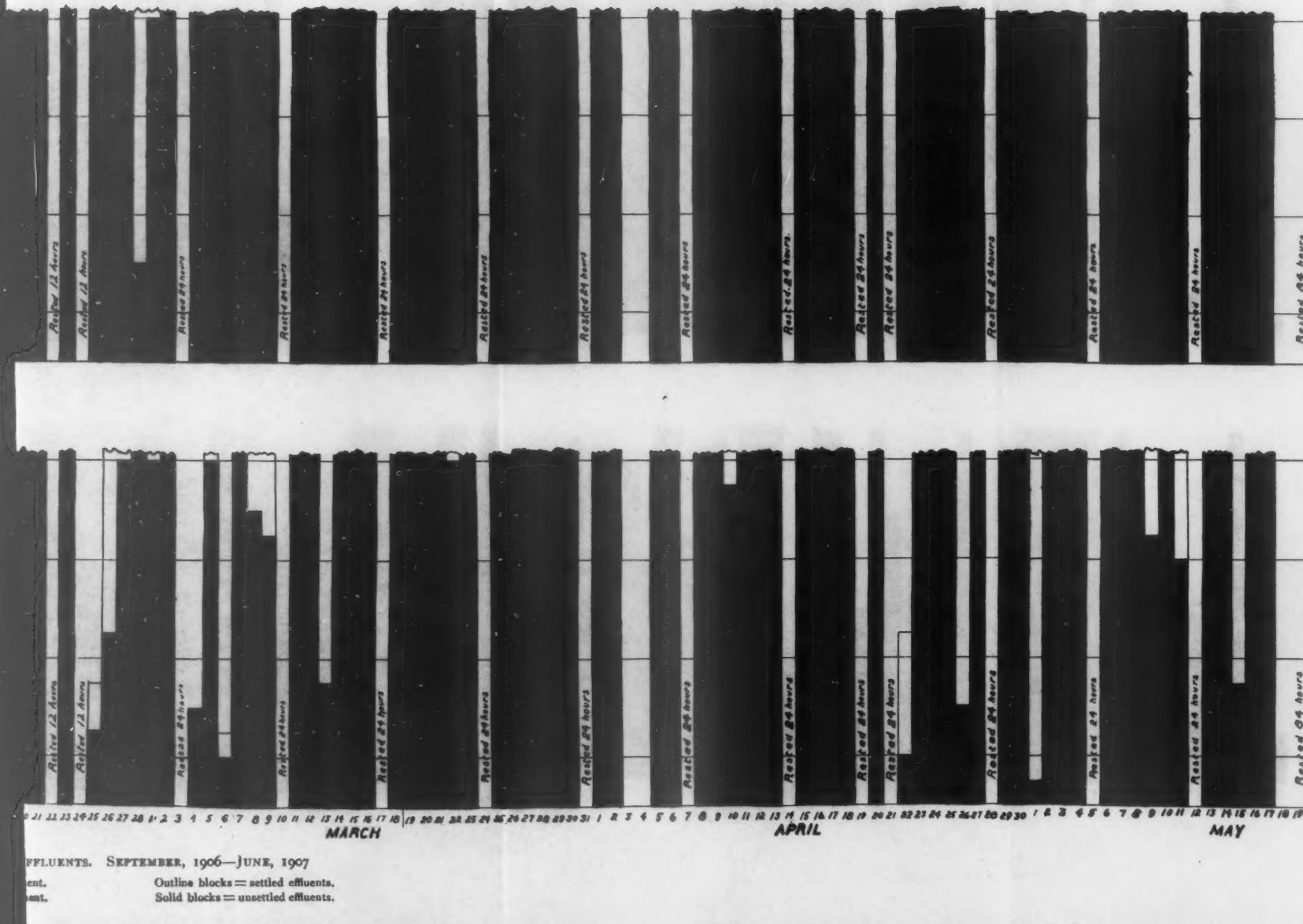
FIG. 18–*B*.—DAILY RECORD OF STABILITY OF SETTLED AND UNSETTLED TRICKLING EFFLUENTS. SEPTEMBER, 1906—JUNE, 1907

Abscissæ = successive dates.
Ordinates = number of days for which sample remained stable at 90°.

Upper line = Filter B effluent.
Lower line = Filter A effluent.

Outline blocks = settled effluents.
Solid blocks = unsettled effluents.

Rested 24 hours
APRIL
MAY



FFLUENTS. SEPTEMBER, 1906—JUNE, 1907

ent. Outline blocks = settled effluents.

ent. Solid blocks = unsettled effluents.

Rested 24 hours
Rested 24 hours
Rested 24 hours
Rested 24 hours
Rested 24 hours
Rested 48 hours
Rested 24 hours
Rested 24 hours
Rested 24 hours
Rested 24 hours
Rested 24 hours
Rested 24 hours
Rested 48 hours
Rested 24 hours
AY
JUNE
JULY

TABLE XXII — Amount and Composition of Sludge Removed from Sedimentation Tanks

Period.	Total gallons sewage passed.	Gallons sludge and water removed.	Per cent. sludge.	Cubic yards wet sludge.	Analysis of Sludge, per Cent.					Pounds per Million Gallons Sewage.			
					Solids.		Organic nitrogen.	Carbon.	Specific gravity.	Solids.		Organic nitrogen.	Carbon.
					Loss.	Fixed.				Loss.	Fixed.		
A.													
September—December 3 . . .	276,000	825	15.5	0.636	4.07	5.07	0.195	0.45	1.049	155.0	193.0	7.40	17.10
December 4—January 14 . . .	151,800	90	90.5	0.405	4.32	5.84	0.190	0.45	1.049	184.5	257.0	8.35	19.80
January 15—April 8	285,200	490	38.0	0.925	3.72	3.81	0.150	0.35	1.034	200.0	206.0	8.06	18.90
April 9—June 29	246,000	900	29.0	1.290	4.22	5.12	0.215	0.30	1.028	361.0	439.0	18.40	25.80
B.													
September—December 3 . . .	276,000	825	10.2	0.420	3.81	3.85	0.223	0.45	1.045	96.5	97.5	5.70	11.40
December 4—January 14 . . .	151,800	90	42.0	0.185	3.99	4.43	0.195	0.38	1.042	82.6	92.1	4.05	7.89
January 15—April 8	285,200	490	30.0	0.730	3.30	3.56	0.220	0.20	1.036	138.0	151.0	9.40	8.50
April 9—June 29	246,000	900	16.0	0.712	4.53	3.39	0.205	0.33	1.025	220.0	165.0	9.96	16.10

lion gallons, the cubic yards of sludge removed were, for the four successive periods, 2.3, 2.7, 3.2, and 5.7 for filter A, and 1.5, 1.2, 2.6, and 2.9 for filter B. The increased values in the last two periods are due to the increased suspended solids in the effluents from the trickling beds during the spring rains. Taking the whole period from September to June, there were removed from the sedimentation tanks, per million gallons of sewage passed, on the crude sewage side, 3.40 cubic yards of sludge, with 237 pounds of volatile solids, 281 pounds of fixed solids, 11.2 of organic nitrogen, and 20.8 of organic carbon. On the septic side, per million gallons of sewage passed, there were 2.14 cubic yards of sludge, containing 136 pounds of volatile solids, 126 pounds of fixed solids, 7.5 pounds of organic nitrogen, and 11 pounds of organic carbon.

The volume of this sludge is evidently considerable. In composition it is naturally not so putrescible as its analysis would indicate, since it consists largely of the humus-like compounds formed in the trickling bed. Nevertheless, in concentrated form it is not generally stable, as shown by the fermentations already alluded to as going on in the sedimentation tanks. Mixed with the rest of the effluent these solids do not putrefy, as shown by the methylene blue tests of the unsettled effluent, and by the fact that nitrites and nitrates showed no diminution in the sedimentation tanks. By itself, however, the sludge will generally putrefy, and if it is removed by sedimentation some means must be found for its disposal. We attempted to purify it by straining through coke without success. Coarse coke allowed it to pass freely and fine coke clogged too rapidly to be of practical use. It will probably be found best under actual working conditions to discharge the tank contents on to sludge beds and dig the resulting deposit into the land. From the inconsiderable putrescibility of the sludge, this method of disposal could be accomplished with ease. It will, however, be a local question in each individual case whether the improvement effected in the trickling effluent by sedimentation compensates for the increased cost of settling and of sludge disposal.

VIII. Disinfection of Trickling Effluents

The trickling filter furnishes the best mechanism now available for accomplishing the primary object of sewage purification — the oxidation, or otherwise rendering stable, of organic matter. Often this is enough; but where shellfish industries or water supplies are menaced the bac-

teria too must be taken into account. For bacterial removal the rapid processes of sewage treatment are entirely inadequate. Comparing the effluent of filter B with the crude sewage, it is apparent that septic tank and trickling bed combined reduced the total number of bacteria from 1,200,000 to 180,000 — a diminution of 85 per cent. Tests for *B. coli* during the summer of 1906 gave the results indicated in Table XXIII, the figures representing the average of thirty-five determinations.

TABLE XXIII — BACTERIA IN SEWAGE AND SEPTIC AND TRICKLING EFFLUENTS

	Bacteria per c.c. Lactose agar at 37°.	*B. coli.* Positive tests* in $\frac{1}{100000}$ c.c.
Sewage	1,300,000	65 per cent.
Trickling filter receiving sewage	750,000	35 per cent.
Septic effluent	1,650,000	66 per cent.
Trickling filter receiving septic effluent	750,000	35 per cent.

* By Jackson bile test.

Evidently during the warm weather there was a multiplication of bacteria in the septic tank, and the removal of total bacteria and of gas-forming organisms by the whole process was under 50 per cent.

These results are as good as can be expected from filters of coarse material, but they do not represent satisfactory bacterial purification. For this reason the Baltimore experts (Baltimore, 1906) suggested secondary filtration through sand for the effluents from their projected trickling filters, in order to avoid possible danger to the shellfish industry of Chesapeake Bay. The Board of Advisory Engineers estimated the cost of works for the complete treatment of 75,000,000 gallons of sewage per day at $3,283,250, of which sum $1,040,750, or over 31 per cent., was for the supplementary treatment on sand filters. The annual cost of operation was estimated at $115,500, of which $55,000, or 48 per cent., was for the supplementary treatment (Baltimore, 1906). This gives some idea of the price which it is necessary to pay for effluents of bacterial purity over and above the cost of rendering the sewage stable and non-putrefactive.

Fortunately a far cheaper and equally efficient method of removing bacteria is now at hand. The application of chemicals as a method of sewage purification — that is, as a method for the removal of organic material — has not proved successful except in rare instances,

with sewage of peculiar composition. When organic stability has been attained, however, and bacterial removal only is desired, the problem becomes a wholly different one. Disinfection of sewage and effluents has been studied by various English observers, most exhaustively by Rideal (1905). The latter observer, in an extensive series of experiments at Guildford, studied the action upon raw and septic sewage, and upon the effluents from contact beds, of hypochlorites produced electrolytically from sea water by the oxychloride process. Great reductions in bacteria were obtained with 30 to 70 parts per million of available chlorine for the crude sewage, 25 to 44 parts for septic sewage, and .5 to 20 parts for contact effluents of varying grades of purity. The removal of *B. coli* was all that could be desired. Examinations of the few organisms remaining in the sewages and effluents after treatment showed them to be largely organisms of the hay bacillus group, aërobic, spore-forming bacteria. Absolute sterilization, however, required very high concentration of chlorine. Since American sewages are weaker than European, and trickling effluents more highly purified than those of ordinary contact systems, the outlook for disinfection seemed more favorable under our conditions, for the less organic matter present the less chlorine will be absorbed and prevented from exerting its disinfectant action. Phelps and Carpenter (1906), in a study of the problem on a laboratory scale, obtained the results indicated in Table XXIV.

TABLE XXIV—Disinfection of Trickling Effluent by Bleaching Powder

(Phelps and Carpenter, 1906)

Experiment No.	Available chlorine. Parts per million.	Organisms Killed. Per Cent. of Initial Numbers.				
		Thirty minutes.	One hour.	Two hours.	Five hours.	Twenty hours.
I	3.5	98.7	. .	97.8	99.6	99.9
	10.6	98.9	. .	98 9	99.7	99.8
	55.0	99.9	. .	99.9	99.9	99.9
II	25.0	. .	99.8	99.9	. .	. .
	37.0	. .	99.94	. .	. .	. .
	100.0	. .	99.97	. .	. .	. .
III	2.0	. .	99.8	99.9	. .	. .
	5.0	. .	99.85	99.9	. .	. .
IV	0.25	. .	65.6	70.9	. .	. .
	0.50	. .	89.2	94.2	. .	. .
V	1.0	. .	81.5	99.1	. .	. .
	1.5	. .	99.6	99.9	. .	. .
VI	5.0	. .	98.2	98.2	. .	. .
	10.0	. .	. .	99.6	. .	. .

It was evident from these experiments that complete sterilization was a practical impossibility. Neither the addition of large amounts of bleaching powder, up to 100 parts of available chlorine per million, nor the storage of the effluent for periods of time up to twenty hours proved entirely effectual. On the other hand, a comparatively low concentration of chlorine applied for two hours gave a very large reduction, the residual organisms, as in Rideal's experiments, being

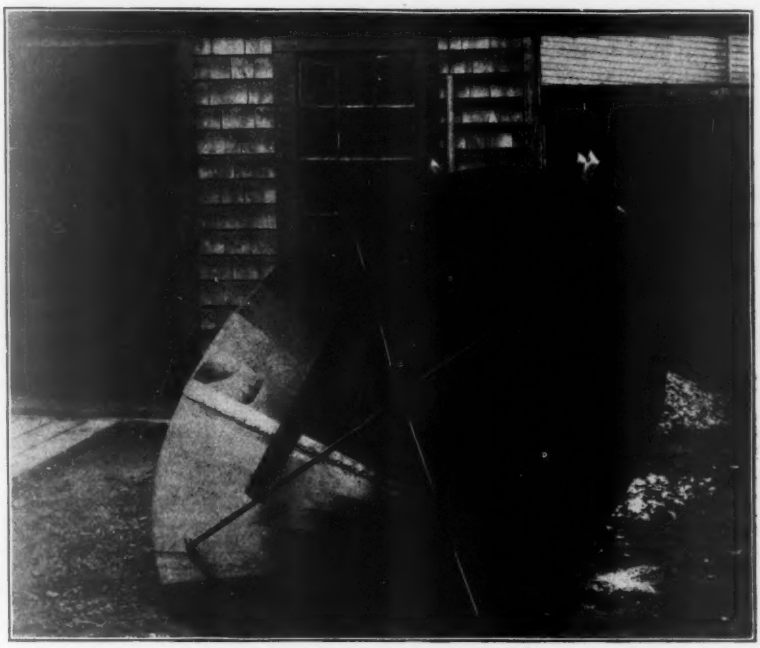


FIG. 19.—VIEW OF SEDIMENTATION TANK BEFORE IT WAS PUT IN PLACE

almost entirely saprophytic spore formers. Sterilization is not feasible, but disinfection is.

It is important to maintain the distinction between absolute sterilization and a reasonable percentage purification such as is obtained in water filtration. A neglect of this discrimination has led to the use of excessive quantities of lime in certain recent German experiments (Schumacher, 1905; Kranepuhl, 1907; Kurpjuweit, 1907). The character of the individual sewage, however, will of course materially affect

the results obtained in a given case. A good efficiency has been reported in recent experiments on the disinfection of septic effluent at Bengal, India. On the other hand, Kellerman, Pratt, and Kimberly (1907) found considerable amounts of chloride of lime necessary for the treatment of septic and contact effluents in Ohio.

In August, 1906, we began to treat the effluent from filter A by adding chloride of lime solution from a small orifice box to the effluent as it flowed into the sedimentation tank. The solution was mixed once a day in a fifty-gallon barrel in such strength that when added to the effluent at the rate of two gallons per hour it would supply the effluent with about five parts per million of available chlorine. It was not possible on such a small scale to regulate the flow accurately, and there was some variation in the amount of available chlorine added to the effluent. This value was determined each day when the samples were taken for bacterial examination. It averaged about five parts per million, and the variation was no more than may be expected in the case of a larger plant with less careful supervision. Samples were examined before the disinfectant was added and at the outflow from the tank after a little less than two hours' contact.

TABLE XXV — EFFICIENCY OF DISINFECTION OF TRICKLING EFFLUENT WITH CHLORIDE OF LIME

(Available Chlorine, Five Parts per Million)

Date.	Organisms per Cubic Centimeter.		Gas Production in Bile Broth.	
	Before treatment.	After treatment.	Before treatment. Dilution, $\frac{1}{10000}$ c.c.	After treatment. Dilution, 1 c.c.
August, 1906				
11	270,000	69	+ 0	+ 0
13	630,000	41	0 0	+ 0
14	135,000	406	+ +	+ 0
15	230,000	21	0 0	0 0
16	250,000	37	+ 0	0 0
18	110,000	40	0 0	+ 0
20	90,000	54	+ 0	0 0
21	220,000	22	0 0	0 0
23	. .	. .	+ 0	0 0
Average	240,000	86	33 per cent.	22 per cent.
Average removal		99.96 per cent.		99.993 per cent.

The results of bacterial examinations on nine different days during the period, as indicated in Table XXV, show a 99.96 per cent. removal of total organisms. With Jackson's bile test positive results were obtained in 33 per cent. of the tests made upon the untreated effluent at a dilution of one millionth, indicating that the organism was present on the average to the extent of about 330,000 per cubic centimeter. After treatment, positive tests were obtained in 22 per cent. of 1 c.c. samples, indicating that on the average there was an organism present in 5 c.c. of effluent. Upon this basis the average removal of fermenting organisms (presumably *B. coli*) was 99.993 per cent.

These results were so favorable as to indicate the entire feasibility of disinfecting the effluent from trickling beds by means of chlorine. Five parts of chlorine, the amount necessary to secure practical disinfection, could be applied at a cost of $1.50 per million gallons of sewage. We desired, however, to compare the efficiency of other disinfecting agents. Johnson and Copeland (1905) obtained good results with copper sulphate, but used amounts of copper and periods of storage which would make the cost of the process prohibitive. When our filters were put in operation after their rest in September, 1906, experiments were begun with copper sulphate. One part of copperas sulphate per million was added to A effluent from October 13 to November 19, and from November 20 to December 2 two parts were used in the same way. During the first period the average of examinations on fourteen days showed 230,000 bacteria per cubic centimeter before treatment and 34,000 afterward — a reduction of 35 per cent. During the second period (with two parts of copper per million) the average of examinations on seven days showed 240,000 bacteria per cubic centimeter before treatment and 18,000 after — a reduction of 92.5 per cent. Evidently copper is inferior to chlorine for the treatment of this effluent, since the cost of one part of copper is about equal to that of five parts of chlorine.

During January and February, 1907, no disinfectant was added to the effluent from filter A. Simple sedimentation showed for the average of fifteen determinations a reduction from 140,000 bacteria to 42,000 — a diminution of 70 per cent. At higher temperatures, when multiplication takes place in the tank, no such reduction would, of course, be observed. As noted above, the tank receiving B effluent showed a considerable net increase of bacteria in the period from October to April.

March 1 experiments were begun with a third disinfectant, sodium benzoate, which has been suggested for use in this connection. In March and April, 0.8 part per million gallons was added, and in May the quantity was doubled. For the first period the average of tests on twenty-six different days showed 140,000 bacteria per cubic centimeter before treatment and 54,000 afterward — a reduction of 62 per cent. For the second period the average of five determinations showed 370,000 bacteria per cubic centimeter before treatment and 84,000 afterward — a reduction of 78 per cent. Evidently sodium benzoate is not an economical disinfectant, since the application of one part per million gallons would cost $1 per million gallons.

There is one important factor to be taken into account in interpreting these results, that of temperature. The action of disinfecting agents follows the velocity laws of other chemical reactions, and rises with an increase of temperature. The chlorine work was, therefore, carried out under somewhat more favorable conditions than the experiments with copper sulphate and sodium benzoate. The difference between chloride of lime and the other agents tested was so great, however, as to leave little question of the practical superiority of chlorine for the treatment of our effluent. Recent work carried out by one of us for the New Jersey State Sewerage Commission at Red Bank, New Jersey, has shown that chlorine disinfection is entirely feasible at a low cost and on a practical scale.

IX. Conclusions as to the Best Methods of Treating Boston Sewage, with an Estimate of Its Approximate Cost

1. *Trickling Beds.* — The main result of this investigation has been to show the feasibility of treating Boston sewage on trickling beds so as to secure organic stability. In the experiments conducted, the filters were operated at a rate of about two million gallons per acre per day, which would call for fifty acres of stone beds for the treatment of the sewage now discharged at Moon Island. A comparison with the 133 acres of contact beds or 1,000 acres of sand beds, which would be necessary for other processes, indicates clearly that for this city the trickling bed offers the most practical method of treatment.

We have found that with good distribution a trickling bed 8 feet deep will operate successfully at all seasons, under local weather con-

ditions. It removes about half the soluble organic matter, yielding an effluent which is somewhat turbid, but stable and well oxygenated. The organic matter present has been so worked over and purified by the bacteria in the filter as to be non-putrescible. Judged by the methylene blue reduction test 93 per cent. of the samples of the effluent are of such stability as to undergo no putrefactive change when kept closed up from the air for four days. Under ordinary conditions of discharge into open water such an effluent would be entirely unobjectionable.

The proper distribution on trickling beds can be attained either by the use of fixed sprinkler heads of the Columbus type, so arranged as to discharge intermittently at frequent intervals, or by the use of the splashing gravity distributors designed at the Experiment Station for this purpose.

With good distribution the trickling beds show no appreciable tendency to clog. During the greater part of the year solid matter accumulates on the surface of the stones throughout the bed, but when this storage reaches a certain point, usually in the early spring, the solids break away and come off in the effluent in a stable condition. In a period covering two years the total amount of solid matter coming off balanced that going on. The filtering material at the end of the experiments was in excellent condition and showed no storage of nitrogen.

Our results point strongly to the advantage of operating trickling beds under conditions as uniform as possible. Resting periods proved distinctly detrimental to the work of the beds, and constant operation is to be recommended rather than any process which involves alternate working and resting periods.

2. *Septic Tanks.* — It appears from our experiments that Boston sewage may be treated in the septic tank with excellent results, and that a period of seven hours is a sufficiently long one. Thus operated an open tank will remove 40 per cent. of the total suspended solids and 60 per cent. of the fixed suspended solids; its effluent shows a decrease of about 25 per cent. in organic nitrogen in solution and a corresponding increase in free ammonia. The septic action on the stored solids is an active one, four-fifths of the organic solids deposited disappearing in solution or as gas. Fixed solids gradually accumulate so as to render it probable that tanks would require cleaning about once in two years.

On the whole, our experiments indicate that the septic tank need

not be used at all in the treatment of Boston sewage. Since November, 1906, when the distribution system was put in order, crude sewage has been treated on one of our trickling beds with perfect success. The effluent from this filter was less frequently putrescible than that from the bed which received septic effluent. The filter taking septic effluent showed a deposit on its floor, due to secondary reducing changes, which was absent from the crude sewage bed. Furthermore, the absence of the odors produced by spraying septic sewage is an advantage of considerable moment in favor of the process of treating fresh sewage. Combined with the saving of the cost of tanks (in the neighborhood of $250,000), these arguments seem to indicate the treatment of crude sewage directly on trickling filters as most desirable. Modern devices for ensuring a thorough preliminary screening should, however, be installed.

3. *Sedimentation of Trickling Effluents.* — The suspended solids which appear in the trickling effluent, though inoffensive, are unsightly, and in many locations might require removal. By a sedimentation of two hours we have found it possible to remove about half the suspended solids. This clarification was accompanied by an improvement in stability.

In the case of Boston the currents of the harbor would be amply competent to care for the solid matter discharged if that matter were of an inoffensive and non-putrescible nature. Experience with the system at present in use has indicated this quite clearly. For a comparatively slight improvement in stability it does not appear to us justifiable to go to the expense of installing secondary sedimentation tanks. The sludge accumulating in such tanks would amount to two or three cubic yards per million gallons of effluent — a serious problem in itself. We are therefore of the opinion that the effluent from the trickling beds may best be discharged directly into the harbor as it comes from the beds. A stable effluent under such conditions could cause no nuisance, and if a submerged discharge were provided its presence would scarcely be detected.

4. *Disinfection of Trickling Effluent.* — The problem of bacterial purification still remains to be considered, since the trickling bed produces organic stability without destroying pathogenic bacteria. In the case of Boston Harbor, with its large contiguous population, its bathers, and its shellfish industry, this aspect is an important one. The experiments carried out during the last two years have made it clear that

the effluents from trickling beds may be so purified bacterially by disinfection with chloride of lime as to be of much better quality than the present streams entering Boston Harbor. This bacterial purification requires about five parts of available chlorine per million gallons, and the cost of treatment would be within moderate limits.

The process of disinfection with chlorine can be applied to crude sewage as well as to trickling effluent, although experiments carried out at the station indicate that about double the amount of chlorine is needed, on account of the reducing action of the organic matter in the sewage. Pending the construction of a trickling filter plant for the treatment of the organic matter in Boston sewage, it might well be purified bacterially by this process at the present Moon Island outfall.

5. *General Plan for the Treatment of the Sewage of the South Metropolitan District.* — The sewage outfall of the south Metropolitan district at Moon Island is the one which threatens most seriously to menace the purity of Boston Harbor, and it is this sewage which will certainly first require some different method of treatment. We have, therefore, considered in a general way the practical problem of dealing with it in the light of the results of our experiments.

The most convenient location for a trickling filter area would be at the calf pasture in Dorchester, near the present pumping station. This is objectionable, however, on account of its proximity to the thickly settled portion of Dorchester. Furthermore, the necessity for excavating about 10 feet of mud and refilling in its place would greatly increase the cost of construction at this point. The same objections apply to certain waste areas on the Neponset marshes which suggested themselves as possibly available. The headland of Squantum would offer an ideal opportunity for building trickling beds, but the difficulties of obtaining land in another town militate against the use of this site.

The southern portion of Thompson's Island would furnish a location free from all the objections to which the other sites are open. On an embankment 1,500 feet long the sewage could be carried from Squantum across to the island, the effluent flowing back along the same embankment to the existing outfall sewer. The pumping station at Dorchester and the tanks and outlet at Moon Island could thus be used without substantial changes. We have made preliminary estimates of the cost of building fifty acres of trickling beds, 8 feet deep, and equipped with the gravity distribution system, and are of the opinion that the cost,

including the embankment with its two sewers, an efficient grit chamber, a reasonable purchase price for the necessary land, grading, stone filling brought to the island by water, concrete construction, and sprinklers, would be in the neighborhood of $1,800,000.

If this capital sum were borrowed at 5 per cent. on a twenty-five year loan the annual expense for interest and sinking fund would be $126,800, paying off the entire cost in the twenty-five year period. As a matter of fact, we see no reason to suppose that at the end of this time the plant would not be good for another twenty-five years without substantial reconstruction. The cost of operation, including extra pumping and supervision of screens and filters, would amount to $70,000 a year, bringing the total cost to about $200,000 a year, or $5.50 per million gallons of sewage treated.[1]

The effluent from the trickling beds, wherever situated, could be further bacterially purified by disinfection with chloride of lime, at a cost of approximately $1.50 per million gallons, or $55,000 annually.

Pending the construction of filters for the removal of putrescible organic matter from Boston sewage, if it should seem desirable to secure bacterial purification, this may be effected by direct treatment of the crude sewage with chloride of lime, which could probably be done for $3 per million gallons, or $110,000 annually.

Experiments are now in progress at the Experiment Station to test the practicability of higher rates of filtration and shallower beds than those used in the experiments on which these calculations are based, as well as on the treatment of sewage and effluents by electrolytically produced chlorine. It is hoped that these experiments may lead to a material reduction in the estimated cost of the purification processes. It seems clear, however, that the combination of trickling filters and chemical disinfection will solve the Boston sewage problem satisfactorily; and in the light of present knowledge these two methods are the most efficient and economical available for the purpose.

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THE WILFLEY TABLE[1]

By ROBERT H. RICHARDS

THIS truly remarkable machine was built on a preliminary scale in May, 1895. The first full-sized table was built by Mr. A. R. Wilfley, and was used in his own mill in Kokomo in May, 1896. The first table sold for installation was placed in the Puzzle Mill, Breckinridge County, in August, 1896.

The mill enthusiasts at first hailed it as the cure for all the ills that flesh is heir to in the milling line. A little later it was found to make losses which were serious, and on this account the table succeeded only to a limited extent in displacing the vanners of the gold mills. Still later, mill men in a number of districts throughout the country made special studies of the faults of the machine, and devised a number of ways of grouping supplementary machines to overcome as far as possible the losses, and at the same time retain the benefit of the extraordinarily large capacity accompanied by the production of clean concentrates for which the machine has become so justly famous. I hope to make an exhibit of some of these methods in an appendix to my book on ore dressing which is now in preparation. These experimenters have not written up the subject, and if they possess all the facts they have not given them out for the benefit of the mining profession at large.

The object of this paper is to obtain the facts and to present them so clearly that their bearing can be seen by all. To this end two complete series of tests have been planned. One (the present paper), to study concentration of galena in presence of quartz; the other (to follow shortly), to study concentration of chalcopyrite in presence of quartz.

Some authorities claim that the table does its best work when treating natural products; by this phrase I mean products which have been

[1] Transactions of the American Institute of Mining Engineers, Toronto meeting, July, 1907.

crushed to pass through a limiting sieve, but have had no other preparation whatever; in consequence they have all sizes of grains of both the heavy valuable mineral and the light waste gangue, ranging from the largest grains that can pass through the sieve down to the finest dust.

Others claim that the ore fed to a Wilfley table should be closely sized before it is fed. That is to say, it should be divided by a series of sieves ranging from coarse to fine into a series of products with sizes of grain ranging from coarse grains to fine grains; and that each of these products, in which the grains of the heavy mineral are of approximately the same diameter as the grains of the light mineral, should be fed to the Wilfley table.

Still a third group of authorities claims that the ore before being fed to a Wilfley table should be classified by a hydraulic classifier, which divides the crushed ore into a series of products ranging, like the sized products, from coarse grains to fine grains, by carrying it in a water current over a series of apertures or vertical pipes, called sorting columns, up through which water currents are passing. These currents are graded from faster to slower, and therefore allow only the heaviest grains to settle down through the first sorting column and out through the spigot; while lighter, smaller grains settle in the second, and still lighter in the third, and so on, diminishing until the last sorting column and spigot give very small grains, and the overflow has the finest grains of all. The classified products differ greatly from the sized products in that the grains of heavy mineral are much smaller in diameter than the light grains with which they settle, and therefore behave in a somewhat different way upon the Wilfley table from the sized products. It should be said that the first spigot product of a classifier differs from the others in having coarse grains of heavy mineral present also.

The usual division of products upon a Wilfley table is easily and naturally made, as shown in Figure 1, *A* being concentrates; *B*, middlings; *C*, tailings, and *D*, slimes. Of these, when natural products are fed, the concentrates, *A*, are nearly clean, heavy mineral, a slight contamination of small grains of quartz being present. The middlings, *B*, carry some large grains and also some small grains of heavy mineral. The tailings, *C*, carry some very small grains of heavy mineral, and the slimes, *D*, carry very minute grains of heavy mineral.

I believe that the small grains of heavy mineral in middlings, *B*,

and tailings, *C*, are of less diameter than the smallest in the concentrates, *A*, and of greater diameter than the majority in the slimes, *D*, and that they belong in middlings and tailings from the law of their existence. The re-running of such middlings upon the same table is therefore not a wise proceeding, and only admissible as an expedient in small establishments when the quantity of middlings is not sufficient to warrant other provision. So much for the speculation before the investigation was made.

The materials for this test were pure white massive quartz for the light mineral, and crystalline galena, nearly free from blende and other impurities, from Joplin, Missouri, for the heavy mineral. The quan-

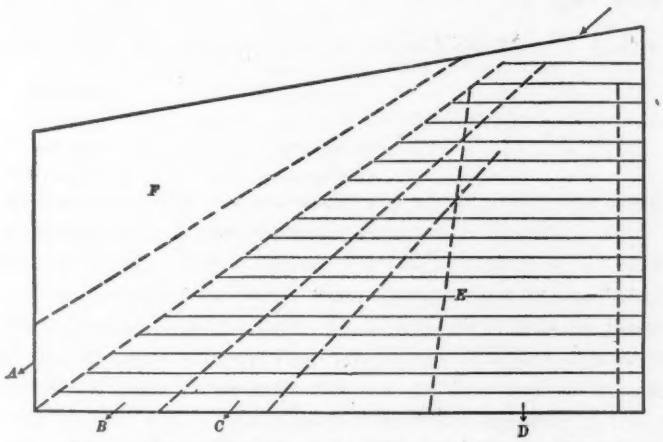

FIG. 1.—USUAL DIVISION OF PRODUCTS ON A WILFLEY TABLE

tities of these impurities were so small as to have little effect on the results. Both minerals were broken down to 2-mm. size, and mixed so as to have approximately 10 per cent. of galena and 90 per cent. of quartz.

The Wilfley table used for the tests had a net working surface of 2 feet by 4 feet. This is the table that has been found very satisfactory for students' work at the Massachusetts Institute of Technology. An error is present to a slight extent in the full-sized table, 16 feet long by 7 feet wide, and to a serious extent in the small Wilfley testing table, 7 feet long, found in some of the schools. It is due to tacking tapered riffle cleats on to a linoleum plane surface, thereby making two

planes: first, the roughing plane over the riffle cleats, *E*, Figure 1; second, the cleaning plane or part where there are no riffles, *F*, Figure 1. These two planes make an angle with each other, or a slight trough, which heaps up the sands deeper than is wise along the line of the tips of the riffle cleats. This error is completely overcome on the little table here used by cutting the riffles down into the wooden surface of the table. The roughing and cleaning planes are therefore one and the same plane. By observing this precaution I believe that this little table is able to do as good work as the full-sized table.

Comparing the little table with the full-sized table as to areas and capacity, assuming that their capacities are proportional to their areas, we have Table I.

TABLE I—AREA AND CAPACITY OF SMALL AND LARGE WILFLEY TABLES

	Little table.	Large table.
Area	8.0 square feet	112.0 square feet
Feed	1.0 kilogram per minute	22.0 tons per 24 hours
Feed	0.75 kilogram per minute	16.6 tons per 24 hours
Feed	0.5 kilogram per minute	11.0 tons per 24 hours

These figures represent the usual range used in practice.

Seventeen runs in all were made; Nos. 1 to 5, inclusive, were made upon natural products, the several feed-products being 2 mm. to 0; 1 mm. to 0; 0.5 mm. to 0; 0.25 mm. to 0; and 2 mm. to 0. Run No. 5, although fed with the same size as No. 1, was fed at a different rate. In making these runs no effort was made to re-run the middlings; first, because the concentrates and tailings would both have been contaminated and would not have shown as well; second, because the middlings themselves would have undergone a change in composition. In consequence of this ruling, the quantities of middlings appear abnormally large.

In these runs the dividing line between concentrates and middlings was chosen so as to make concentrates nearly clean to the eye. The dividing line between middlings and tailings was chosen so as to keep all the large grains of heavy mineral in the middlings. The four products—concentrates, middlings, tailings, and slimes—were sized on a series of sieves, and the quartz in them determined by dissolving out the galena in hydrochloric acid. The galena was determined by difference.

Runs Nos. 6 to 11, inclusive, were all upon sized products, and the results obtained are given in Table II.

TABLE II — SIZES AND WEIGHTS OF MATERIALS FED TO TABLE. TESTS NOS. 6 TO 11

Run No.	Sieves Diameter.		Actual Weights.
	Through.	On.	Fed.
	mm.	mm.	kg.
6	2.0	1.4	12.15
7	1.4	1.0	6.74
8	1.0	0.75	4.93
9	0.75	0.5	2.85
10	0.5	0.36	1.70
11	0.36	0.28	1.55
. .	0.28	0.0	3.08
			33.00

The total quantity weighed 33 kg., of which 30 kg. was quartz and 3 kg. was galena. The guiding was done simply to make clean concentrates and tailings. The middlings were in every case re-run until they could not be further reduced without contaminating the concentrates or the tailings. Where a sized ore is free from included grains and from any middle weight mineral, the feeding back of the middlings on the same table is logically good practice, because the middlings product is simply a mixture of concentrates and tailings; therefore, they could be fed back on the same table and disappear entirely without harm to concentrates or tailings.

Runs Nos. 12 to 17, inclusive, were made upon sorted or classified products. The classifier (Figure 2) had twelve closed spigots or blind spigots; that is to say, spigots which discharged sand into 2-gallon bottles as fast as it came, but discharged no water. The sorting columns were of 0.5-inch pipe, squared at the top and 3 inches long. Expressed in millimeters per second, the rising currents in the successive sorting columns were: 105, 85, 69, 55, 45, 36, 29, 23, 19, 15, 12, 10, respectively. The thirteenth spigot had no rising current, and it was simply a safety spigot to prevent any accumulation of sand that was too light to go down in the twelfth and too heavy to go over into the overflow. This apparatus gives a set of products beautifully classified.

To define the classified products more completely, a small aliquot

TABLE III — DISTRIBUTION OF QUARTZ AND GALENA IN RUNS NOS. 12 TO 17

Run No.		12			13			14					
No. of spigot		1			2			3			4		
Actual weight in kg.		15.110			15.775			11.175			5.170		
Rising current, mm. per second		105			85			69			55		
Through.	On.	Quartz.	Galena.	Middlings.	Quartz.	Galena.	Middlings.	Quartz.	Galena.	Middlings.	Quartz.	Galena.	Middlings.
mm.	mm.												
2.83	2.49	0.052	0.004	0.007	. .	. .	. .	. .	. .	. .	. .	. .	. .
2.49	2.06	2.408	0.709	0.021	1.517	. .	. .	0.213	. .	. .	. .	. .	. .
2.06	1.63	17.170	7.216	0.085	20.299	. .	0.006	3.617	. .	0.003	0.112	. .	. .
1.63	1.44	9.885	7.650	0.112	20 805	0.004	0 009	6.510	0.002	0 003	0.394	. .	. .
1.44	1.27	9.381	8.476	0.118	19.856	0.003	0 013	12.635	0 003	0 004	1.210	. .	. .
1.27	1.10	2.480	3.391	0.010	15.746	0.004	0.016	14.249	0 002	0 002	3.475	. .	0.001
1.10	0.97	1.945	3.742	0.022	5.161	0.006	0.011	14.339	0.003	0.001	2.573	. .	0.001
0.97	0.84	2.041	5.435	0.025	5.925	0.037	0.023	15.208	0 027	. .	9.530	0.006	. .
0.84	0.68	0 861	3.914	0 020	2.734	0 063	0.017	10.646	0.018	. .	12.793	0.008	. .
0.68	0.57	0 535	3.479	0 009	1.527	0.147	0.013	7.499	0 030	. .	20.128	0.037	. .
0.57	0.45	0.356	4.143	. .	1.558	0.865	. .	8.795	0.167	. .	26 312	0.056	. .
0.45	0.36	0 100	1.634	. .	0.217	0.678	. .	1.437	0.203	. .	9.741	0.070	. .
0.36	0.28	0.068	1.407	. .	0.107	1.215	. .	0.942	0.678	. .	6.502	0.275	. .
0.28	0.24	0.022	0.457	. .	0 028	0.517	. .	0.190	0.455	. .	1.638	0.489	. .
0.24	0.20	0.016	0.258	. .	0 015	0.414	. .	0.124	0 825	. .	0.667	0.892	. .
0.20	0.15	0.010	0.145	. .	0.009	0.233	. .	0.045	0.594	. .	0.223	1 107	. .
0.15	0.12	0.007	0.089	. .	0.005	0.107	. .	0.013	0.295	. .	0 068	0.715	. .
0.12	0.10	0.001	0.018	. .	0.003	0 025	. .	0.007	0 093	. .	0.037	0.458	. .
0.10	0.08	0.007	0 037	. .	0.005	0.029	. .	0.010	0.102	. .	0.025	0.301	. .
0.08	0.00	0.007	0.037	. .	0.009	0.023	. .	0.090	0.050	. .	0.012	0.132	. .
Total		47.352	52.261	0.429	95.526	4.370	0.108	96.569	3.587	0.013	95.440	4.546	0.002
Settling ratio		1.58			4.11			3.93			3.26		

TABLE III — *Continued*

Run No.		15				16						17							
No. of spigot		5		6		7		8		9		10		11		12		Overflow.	
Actual weight in kg.		2.280		1.950		1.182		0.389		0.962		0.765		0.651		0.705		1.860	
Rising current, mm. per second		45		36		29		23		19		15		12		10			
Through.	On.	Quartz.	Galena.	Quartz.	Galena.	Quartz.	Galena.	Quartz.	Galena.	Quartz.	Galena.	Quartz.	Galena.	Quartz.	Galena.	Quartz.	Galena.	Quartz.	Galena.
mm.	mm.																		
2.83	2.49	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .
2.49	2.06	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .
2.06	1.63	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .
1.63	1.44	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .
1.44	1.27	0.031	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .
1.27	1.10	0.132	. .	. .	. .	0.008	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .
1.10	0.97	0.184	. .	0.015	. .	0.017	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .
0.97	0.84	1.467	. .	0.082	. .	0.042	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .
0.84	0.68	5.161	. .	0.949	. .	0.220	. .	. .	. .	0.010	. .	. .	. .	. .	. .	. .	. .	. .	. .
0.68	0.57	5.200	0.009	1.668	. .	3.133	. .	0.150	0.101	0 073	. .	0.026	. .	. .	. .	. .	. .	. .	. .
0.57	0.45	29.990	0.057	16.732	. .	9.086	0.084	5.156	0.125	1.850	0.135	0.040	. .	. .	. .	. .	. .	. .	. .
0.45	0.36	25.038	0.026	18.590	0.380	36.110	0.338	20.250	0.125	13.185	0.260	6.799	0.171	1.251	0.015	0.114	0.014	0.169	0.238
0.36	0.28	19 164	0.119	34.011	0.272	15.539	0.160	23.252	0.225	14.806	0.291	3.980	0.026	3.961	0.104	0.528	0.057	0.185	0.195
0.28	0.24	4.779	0.132	9.752	0.082	17.499	0.253	26.435	0.350	29.790	0.364	23.061	0.132	12.375	0.134	5.083	0.129	0.723	0.486
0.24	0.20	2 280	0.435	8.884	0.257	7.127	0.296	12.740	0.275	17.320	0 281	29.820	0.211	25.773	0.223	11.593	1.157	2.243	0.438
0.20	0.15	0 725	1.019	2.171	0.406	3.344	0.828	3.755	0.325	11.813	0.416	18.685	0.303	26.653	0.298	21.415	1.999	10.116	0.950
0.15	0.12	0.242	1.612	1.011	1.273	0.650	0.769	0.901	0.526	2.275	0.499	5.455	0.329	11.615	0.268	11.464	1.171	8.575	0.522
0.12	0.10	0.119	0 663	0.205	1.232	0.507	2.111	0.951	2.203	1.299	2.005	3 321	1.186	7.787	0.819	20.500	2.413	28.520	1.805
0.10	0.08	0.018	0.474	0.092	1.140	0.228	1.647	0.225	1.902	0.416	2.910	1.700	4.744	3.529	5.182	17.475	4.982	35.460	9.372
0.08	0.00	0.048	0.879	0.046	0.739														
Total		94.578	5.425	94.208	5.781	93.510	6.486	93.815	6.157	92.837	6.261	92.887	7.102	92.944	7.043	88.172	11.922	85.991	14.006
Settling ratio		3.19		2.62		2.49		2.21		2.21		2.74		2.46		1.28		1.10	

part of each was sized, photographed, and analyzed. The photograph, Figure 3, shows to the eye the distribution of sizes in each spigot. Table III shows the distribution of quartz and galena in the different sizes of each spigot. Expressed in millimeters, the sieve sizes used were: 2.83, 2.49, 2.06, 1.63, 1.44, 1.27, 1.10, 0.97, 0.84, 0.68, 0.57, 0.45, 0.36, 0.28, 0.24, 0.20, 0.15, 0.12, 0.10, 0.08. The middlings picked out and weighed for the first four spigots consisted of blende and galena included grains, with some free blende grains. Their use here is sim-

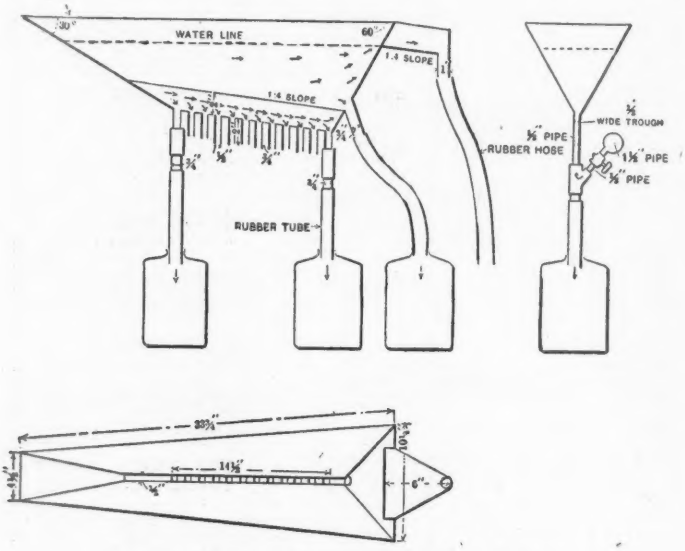

FIG. 2.—CLASSIFIER USED FOR RUNS NOS. 12 TO 17

ply to show how nearly pure the galena was. The settling ratios are of special interest; for example, at the foot of spigot No. 4 we have the settling ratio, 3.26, which signifies that in spigot No. 4 the average diameter of the quartz grains is 3.26 times the average diameter of the galena grains. The method of computing these ratios is given in my paper, "Close Sizing before Jigging."[1] It was thought wiser to combine the spigots somewhat instead of making twelve separate runs; accordingly, the six runs were fed with products as follows: First spigot; second spigot; third and fourth together; fifth and sixth

[1] Trans., XXIV, 449, 450 (1894).

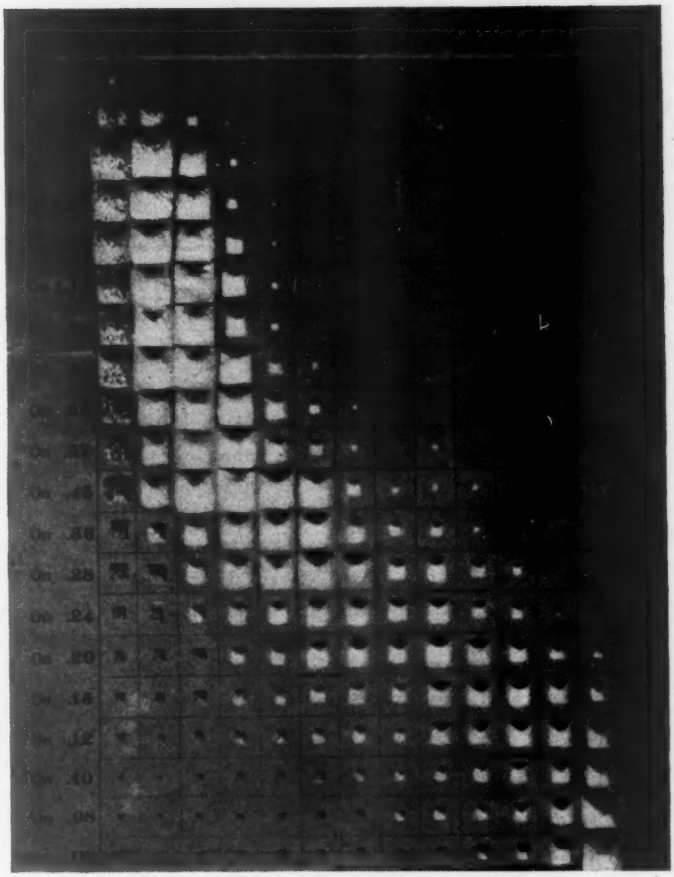

FIG. 3.—DISTRIBUTION OF SIZES BY THE CLASSIFIER

together; seventh, eighth, and ninth together; tenth, eleventh, and twelfth together.

The first five runs on natural products computed on the basis of a 100-ton lot, and to the rate of feeding of a full-sized table, gave products shown in Table IV.

TABLE IV — RESULTS OF RUNS NOS. 1 TO 5

	Run No. 1.	Run No. 2.	Run No. 3.	Run No. 4.	Run No. 5.
Size of feed	mm. 2 to 0	mm. 1 to 0	mm. 0.5 to 0	mm. 0.25 to 0	mm. 2 to 0
Rate of feed per twenty-four hours	Tons. 22	Tons. 22	Tons. 11	Tons. 11	Tons. 11
Concentrates	4.114	2.973	4.667	5.343	2.808
Middlings	21.486	20.750	25.961	21.028	45.538
Tailings	72.856	72.903	62.813	60.487	50.688
Slimes	1.544	3.374	6.539	13.142	0.966
Total	100.000	100.000	100.000	100.000	100.000

The next six runs on sized products, computed on the basis of a 100-ton lot, and to the rate of feeding of a full-sized table, gave products shown in Table V.

TABLE V — RESULTS OF RUNS NOS. 6 TO 11

	Run No. 6.	Run No. 7.	Run No. 8.	Run No. 9.	Run No. 10.	Run No. 11.
Size of feed	mm. 2 to 1.4	mm. 1.4 to 1	mm. 1 to 0.75	mm. 0.75 to 0.50	mm. 0.50 to 0.36	mm. 0.36 to 0.28
Rate of feed per twenty-four hours,	Tons. 22	Tons. 16.6	Tons. 11	Tons. 11	Tons. 11	Tons. 11
Concentrates	6.537	9.728	12.064	13.168	12.171	15.137
Middlings	1.647	1.901	1.694	1.602	5.310	3.170
Tailings	91.816	88.371	86.242	85.230	82.519	81.693
Slimes	0.000	0.000	0.000	0.000	0.000	0.000
Total	100.000	100.000	100.000	100.000	100.000	100.000

The last six runs, computed on the basis of 100-ton lots, and to the rate of feeding of a full-sized table, gave products shown in Table VI.

TABLE VI—RESULTS OF RUNS NOS. 12 TO 17 COMPUTED TO FULL-SIZED TABLE

	Run No. 12.	Run No. 13.	Run No. 14.	Run No. 15.	Run No. 16.	Run No. 17.
Classifier spigots, numbers that were fed . .	1	2	3, 4	5, 6	7, 8, 9	10, 11, 12
Classifier currents, mm. per second through which grains settled	105	85	55.4	36.3	19.1	10
Rate of feed to Wilfley, twenty-four hours .	Tons. 11	Tons. 11	Tons. 16.6	Tons. 11	Tons. 11	Tons. 11
Concentrates	49.649	3.950	3.398	4.940	5.7165	4.980
Middlings	5.534	1.307	0.663	0.828	1.0435	4.262
Tailings	44.817	94.743	95.939	94.232	93.240	90.758
Slimes	0.000	0.000	0.000	0.000	0.000	0.000
Total	100.000	100.000	100.000	100.000	100.000	100.000

Comparing the seventeen runs as to quantity of the products without looking at the quality, it will be noticed at once that the concentrates and tailings in runs Nos. 6 to 11 and Nos. 12 to 17 are very much larger in quantity than these products in runs Nos. 1 to 5; while the middlings are very much smaller in quantity.

A comprehensive table of all seventeen runs is given in Table VII, which shows the proportions of concentrates, middlings, tailings, and slimes in each, and also the percentage of galena and quartz in the various products.

Tables VIII, IX, X, and XI give the weights in tons of the different sizes, and also the proportion of quartz and galena in each product by sizes.

In comparing the analyses of the concentrates of these five runs (Table VIII), we see a very remarkable similarity in the behavior of the quartz and galena through all five runs. The coarser sizes and the finer sizes are almost clean galena, being nearly free from quartz. At a point somewhere a little below the middle, the quartz rises to a maximum, which in the first run reaches 18.99 per cent. of quartz, in the third run reaches 7.38 per cent. of quartz, and in the fifth run reaches 13.80 per cent. of quartz.

Comparing the different analyses of the middlings (Table IX), we find the galena among the very largest and smallest grains gives a very high percentage, and down to a little below the middle the galena runs down to a very low percentage, while the quartz behaves just in the opposite way. This is analogous to the composition of the concentrates.

TABLE VII—Summary of Results of Runs Nos. 1 to 17

No. of run.	Size.	Rate of Feeding.		Composition of the Feed.		Percentage of the Products.				Composition of Products.								Per Cent. of Total Galena.				Total quantity actually fed.
		Kilogram per minute.	Tons 24 hours, large table.	Quartz.	Galena.	Concentrates.	Middlings.	Tailings.	Slimes.	Concentrates.		Middlings.		Tailings.		Slimes.		Concentrates.	Middlings.	Tailings.	Slimes.	
										Quartz.	Galena.	Quartz.	Galena.	Quartz.	Galena.	Quartz.	Galena.					
	mm.			Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Kg.
1	2 to 0	1.0	22.0	90.91	9.09	4.11	21.48	72.87	1.54	9.92	90.08	76.42	23.58	99.49	0.51	81.10	18.90	39.20	53.34	3.82	3.64	11.00
2	1 to 0	1.0	22.0	90.91	9.09	2.97	20.75	72.91	3.37	8.50	91.50	73.37	26.63	99.39	0.61	90.29	9.71	34.58	57.34	4.72	3.36	11.00
3	0.5 to 0	0.5	11.0	90.91	9.09	4.67	25.98	62.81	6.54	2.40	97.60	84.10	15.90	99.10	0.90	87.82	12.18	44.86	41.98	5.44	7.72	11.00
4	0.25 to 0	0.5	11.0	90.91	9.09	5.34	21.03	60.49	13.14	2.27	97.73	87.16	12.84	98.39	1.61	90.04	9.96	51.48	27.59	8.20	12.73	11.00
5	2 to 0	0.5	11.0	90.91	9.09	2.80	45.67	50.30	1.23	4.66	95.34	86.29	13.71	99.71	0.29	85.38	14.62	29.06	67.79	1.62	1.53	9.63
6	2 to 1.4	1.0	22.0	92.60	7.40	6.54	1.65	91.81	. .	0.77	99.23	40.33	59.67	99.96	0.04	. .	. .	87.43	12.05	0.52	. .	12.08
7	1.4 to 1	0.75	16.6	89.08	10.92	9.73	1.90	88.37	. .	0.77	99.23	76.90	23.10	100.00	0.00	. .	. .	96.43	3.57	0.00	. .	6.74
8	1 to 0.75	0.5	11.0	87.32	12.68	12.06	1.69	86.25	. .	0.99	99.01	83.00	17.00	99.91	0.09	. .	. .	97.62	1.80	0.58	. .	4.93
9	0.75 to 0.5	0.5	11.0	87.15	12.85	13.15	1.60	85.25	. .	2.50	97.50	77.40	22.60	99.65	0.35	. .	. .	96.58	2.29	1.13	. .	2.845
10	0.5 to 0.36	0.5	11.0	85.92	14.08	12.18	5.31	82.51	. .	0.69	99.31	80.03	19.97	99.76	0.24	. .	. .	90.57	7.95	1.48	. .	1.72
11	0.36 to 0.28	0.5	11.0	85.70	14.30	15.10	3.17	81.73	. .	2.14	97.86	84.67	15.35	99.56	0.44	. .	. .	94.60	3.10	2.30	. .	1.59
	Classifier																					
12	1st spigot	0.5	11.0	49.82	50.18	49.65	5.53	44.82	. .	0.74	99.26	86.15	13.85	99.71	0.29	. .	. .	98.21	1.53	0.26	. .	13.60
13	2d spigot	0.5	11.0	95.21	4.79	3.95	1.31	94.74	. .	1.38	98.62	66.05	33.95	99.64	0.36	. .	. .	81.35	10.72	7.93	. .	14.197
14	3 and 4 spigot	0.75	16.6	96.23	3.77	3.40	0.66	95.94	. .	1.15	98.85	65.57	34.43	99.80	0.20	. .	. .	88.95	5.98	5.07	. .	14.629
15	5 and 6 spigot	0.5	11.0	94.39	5.61	4.94	0.83	94.23	. .	1.65	98.35	71.10	28.90	99.45	0.55	. .	. .	86.66	4.29	9.05	. .	3.745
16	7, 8, 9 spigot	0.5	11.0	93.74	6.26	5.72	1.04	93.24	. .	1.16	98.84	83.75	16.25	99.54	0.46	. .	. .	90.58	2.90	6.52	. .	2.28
17	10, 11, 12 spigot	0.5	11.0	93.73	6.27	4.98	4.26	90.76	. .	0.38	99.62	83.72	16.28	99.34	0.66	. .	. .	79.38	10.69	9.93	. .	1.9

Comparing the tailings of the five runs (Table X), we note that the galena appears only to a very slight degree in any of the tailings until we get down to the smaller sizes, and there we have figures that rise to an almost alarming size, the first run giving 17.5 per cent. of galena in the finest size; the second, 17.8 per cent.; the fifth run giving 12.17 per cent. in the finest size.

The slimes (Table XI), which have a serious quantity of material only in the finest size, have also a serious percentage of lead in that finest size. The other percentages of lead are generally much smaller. There are three exceptions, in the second, third, and fourth runs, where the percentages run high in the larger sizes, but the quantity is so small that these losses are insignificant.

Commenting upon runs Nos. 6 to 11 (Table XII), as compared with runs Nos. 1 to 5, we note immediately that the concentrates all the way through are almost pure galena with scarcely any quartz, and the tailings are almost pure quartz and scarcely any galena. The middlings, as remarked before, are so small in quantity that they affect the runs but little, and when we consider that they can go directly back on to the table in the continuous run, they do not affect the result at all. This set of runs, Nos. 6 to 11, therefore appears to distance runs Nos. 1 to 5 in the competition. There is really no comparison, since runs Nos. 1 to 5 are not in the same class with them.

Comparing the concentrates of runs Nos. 12 to 17 (Table XIII), we see in the first place an enormous heaping up of concentrates in run No. 12. The weight, forty-nine tons, is more than double the weight of all the other five runs in this set put together. This heaping up of the great quantity of concentrates on the table which treats the first spigot of a classifier is one of the prominent features of the use of a classifier in preparation for feeding Wilfley tables. If we look at the total percentages of galena and quartz in the concentrates of run No. 12, we see that they contain 99.26 per cent. of galena and 0.74 per cent. of quartz. This makes an extremely good showing, and one which bids for favorable consideration of the classifier set.

Looking at the later spigots, that is to say, runs Nos. 13 to 17, inclusive, in the analyses, we see that the percentage of quartz looks high in the coarser sizes. This would seem a serious disadvantage if it were not for the fact that these products which have the high percentages of quartz are so small in quantity that the quartz cuts scarcely any figure in the final percentage of quartz in the concentrates. Alto-

gether this set of concentrates is so good that it would be accepted by any mill, even the Missouri mills, where such clean concentration is required.

Looking at the middlings (Table XIV), we see that the quantity is extremely small, and can be made to disappear in a continuous run by feeding them back on to the table without harming either the concen-

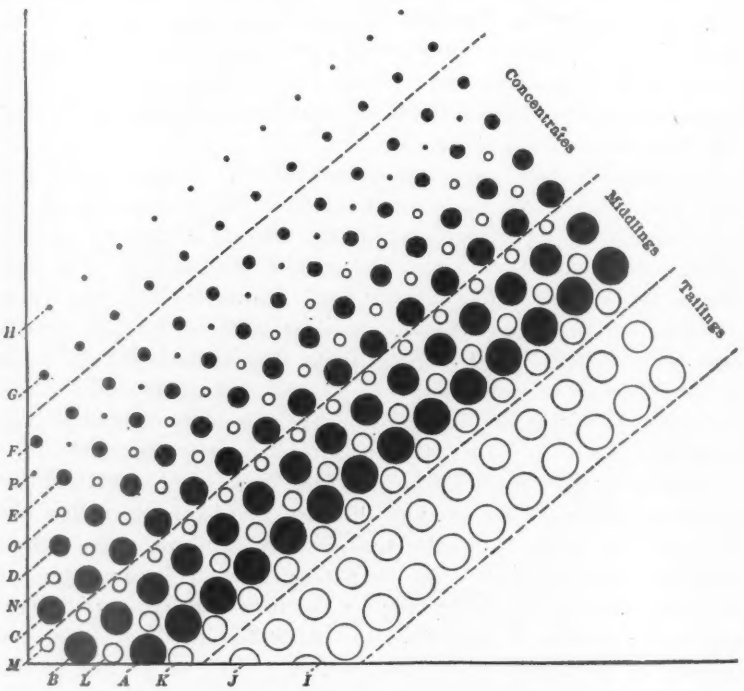

FIG. 4.—IDEAL SKETCH OF THE ARRANGEMENT OF GRAINS BY A WILFLEY TABLE

trates or the tailings. They have, however, some very interesting features that are worthy of note. The galena in the twelfth run runs high in the coarse and in the fine, and very low in the middle sizes, there being a great heaping up of quartz in this part. This same point is true in the sixteenth and seventeenth runs to a very marked degree. It is again true to a less marked degree in the fourteenth and fifteenth runs, and it appears not to be true at all in the thirteenth run.

Looking at the tailings (Table XV), we see that run No. 12 stands

out preëminent, having only 0.29 per cent. of galena in the whole tailings, and the tailings of runs Nos. 13 to 17 are very low in galena, and would probably pass in any concentrating establishment.

We have one feature here which does not and cannot happen in sized runs, Nos. 6 to 11—viz., the tailings get richer in galena down to the finer sizes; but when we look at the tonnage we find that there is scarcely any weight of material down in those sizes, and therefore this loss is not serious and does not bring up the percentage of galena in the final tailings to a serious extent.

Figure 4 is an ideal sketch of what happens at the discharging corner of a Wilfley table. Running from coarse on the lower edge to fine on the upper, *A, B, C, D, E, F, G,* and *H* represent the different sizes of galena. It appears that they arrange themselves approximately according to this order on the Wilfley table. In like manner, the quartz grains arrange themselves approximately in order of size, beginning at the lower edge with the largest grade and running smaller and smaller upwards, as indicated by the letters *I, J, K, L, M, N, O,* and *P*. The slimes at once take off the galena (*H*), and the quartz (*P*). These finest of all grains have not sufficient weight to hold them up to the upper edge, where mathematical logic would place them. They therefore go into the slimes. The next grade, *G* (galena), and *O* (quartz), are not fine enough to go into the slimes nor coarse enough to stand up against the water current in the position shown in the sketch. These grains are found, therefore, sprinkled through the concentrates, middlings, and tailings. See the heaping up of galena in the small sizes in Tables VIII, IX, and X.

TABLE VIII — PROPORTION OF QUARTZ AND GALENA IN PRODUCTS

NOTE. — Concentrates sized and weighed. The weights are computed in tons and fractions of a ton on the 100-ton basis.

Sizes.		Run No. 1.	Run No. 2.	Run No. 3.	Run No. 4.	Run No. 5.
Through.	On.					
mm.	mm.	Ton.	Ton.	Ton.	Ton.	Ton.
. .	2.06	0.017	. .	. .	. .	0 009
2 06	1.63	0.059	. .	. .	. .	0.037
1.63	1.44	0.066	. .	. .	. .	0.054
1.44	1.27	0.112	. .	. .	. .	0.076
1.27	1.10	0.084	. .	. .	. .	0.049
1.10	0.97	0.120	0 003	. .	. .	0.079
0.97	0.84	0.174	0.012	. .	. .	0.104
0.84	0.68	0.206	0.027	. .	. .	0.128
0.68	0.57	0.245	0.048	. .	. .	0.138
0.57	0.45	0.506	0.280	0.225	. .	0.288
0.45	0 36	0.402	0.141	0.322	. .	0.201
0.36	0.28	0.445	0.465	1.000	0.227	0.303
0 28	0.24	0.306	0.304	0.386	0.081	0.179
0 24	0.20	0.375	0 370	0.586	0.700	0 230
0 20	0.15	0.307	0.324	0.483	0.997	0.218
0.15	0.12	0.209	0.313	0.483	0.958	0.213
0.12	0.10	0.110	0.207	0.271	0.397	0.082
0.10	0.08	0.180	0.235	0.404	0.871	0.229
0.08	0.00	0.182	0.244	0.507	1.092	0.191
Total tons		4.114.	2.973	4.667	5.343	2.808

ANALYSES OF THE ABOVE PRODUCTS GIVING PERCENTAGES OF GALENA (PbS) AND QUARTZ (SiO_2)

Sizes.		Run No. 1.		Run No. 2.		Run No. 3.		Run No. 4.		Run No. 5.	
Through.	On.	Galena.	Quartz.	Galena.	Quartz.	Galena.	Quartz.	Galena.	Quartz.	Galena.	Quartz.
mm.	mm.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
. .	2.06	100.00	0.00	. .	. .	. .	. .	. .	. .	100.00	0.00
2.06	1.63	99.77	0.23	. .	. .	. .	. .	. .	. .	97.56	2.44
1.63	1.44	99.80	0.20	. .	. .	. .	. .	. .	. .	100.00	0.00
1.44	1.27	99.88	0.12	. .	. .	. .	. .	. .	. .	99 87	0.13
1.27	1.10	99.76	0.24	. .	. .	. .	. .	. .	. .	99.29	0.71
1.10	0.97	99.43	0.57	100 00	0.00	. .	. .	. .	. .	99.28	0.72
0.97	0.84	98.42	1.58	99.72	0.28	. .	. .	. .	. .	99.80	0.20
0.84	0.68	96.54	3.46	99.90	0.10	. .	. .	. .	. .	99.55	0.45
0.68	0.57	94.47	5.53	100.00	0.00	. .	. .	. .	. .	99.52	0.48
0.57	0.45	91.05	8.95	100.00	0.00	99.61	0.39	. .	. .	97.67	2.33
0.45	0.36	83.81	16.19	99.81	0.19	99.71	0.29	. .	. .	93.34	6.66
0 36	0.28	81.24	18.76	99.74	0.26	99.48	0.52	96.56	3.44	89.24	10.76
0.28	0.24	81.01	18.99	99.16	0.84	99.36	0.64	96.67	3.33	86.20	13.80
0.24	0.20	84.39	15.61	98.25	1.75	97.81	2.19	99.24	0.76	88.21	11.79
0.20	0.15	89.48	10.52	98.02	1 98	93.14	6.86	98.54	1.46	92.92	7.08
0.15	0.12	95.08	4.92	98.78	1.22	92.62	7.38	96.84	3.16	97.52	2.48
0.12	0.10	95.08	4.92	99 32	0.68	95.35	4.65	95.54	4.46	99.03	0.97
0.10	0.08	97.74	2.26	99.57	0.43	98.71	1.29	96.66	3.34	99.65	0.35
0.08	0.00	99.45	0.55	99.62	0.38	99.40	0.60	98.72	1.28	99.63	0.37
Concentrates before sizing		90.08	9.92	91.50	8.50	97.60	2.40	97.73	2.27	95.34	4.66

TABLE IX — PROPORTION OF QUARTZ AND GALENA IN PRODUCTS

NOTE. — Middlings sized and weighed and the weights computed in tons and fractions of a ton on the 100-ton basis.

SIZE. On.	Run No. 1.	Run No. 2.	Run No. 3.	Run No. 4.	Run No. 5.
mm.	Tons.	Tons.	Tons.	Tons.	Tons.
2.06	0.132	. .	. .	. .	0.206
1.63	0.795	. .	. .	. .	1.595
1.44	0.783	. .	. .	. .	2.134
1.27	1.202	. .	. .	. .	2.986
1.10	0.954	. .	. .	. .	2.438
0.97	1.056	0.292	. .	. .	3.178
0.84	1.552	1.330	. .	. .	4.793
0.68	2.021	0.329	. .	. .	5.113
0.57	1.865	1.350	. .	. .	4.323
0.45	3.112	3.203	2.171	. .	8.871
0.36	2.336	2.680	3.117	. .	3.144
0.28	2.536	3.945	5.955	0.402	3.655
0.24	0.848	1.436	4.805	1.684	1.079
0.20	1.230	2.932	3.698	4.729	0.969
0.15	0.648	1.551	4.362	4.713	0.581
0.12	0.207	0.893	0.481	3.600	0.223
0.10	0.075	0.299	0.418	2.296	0.050
0.08	0.061	0.286	0.601	2.216	0.054
0.00	0.093	0.224	0.373	1.328	0.146
Total tons . .	21.486	20.750	25.981	21.028	45.538

ANALYSES OF THE ABOVE PRODUCTS GIVING PERCENTAGES OF GALENA (PbS) AND QUARTZ (SiO_2)

SIZE.	RUN NO. 1.		RUN NO. 2.		RUN NO. 3.		RUN NO. 4.		RUN NO. 5.	
On.	Galena.	Quartz.	Galena.	Quartz.	Galena.	Quartz.	Galena.	Quartz.	Galena.	Quartz.
mm.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
2.06	73.47	26.53	. .	. .	. .	. .	. .	. .	38.43	61.57
1.63	75.39	24.61	. .	. .	. .	. .	. .	. .	41.68	58.32
1.44	69.47	30.53	. .	. .	. .	. .	. .	. .	30.21	69.79
1.27	62.80	37.20	. .	. .	. .	. .	. .	. .	22.69	77.31
1.10	54.75	45.25	. .	. .	. .	. .	. .	. .	18.04	81.96
0.97	43.80	56.20	90.46	9.54	. .	. .	. .	. .	13.85	86.15
0.84	31.40	68.60	89.46	10.54	. .	. .	. .	. .	11.43	88.57
0.68	20.10	79.90	81.60	18.40	. .	. .	. .	. .	9.92	90.08
0.57	16.70	83.30	69.23	30.77	. .	. .	. .	. .	9.60	90.40
0.45	11.30	88.70	37.50	62.50	66.66	33.34	. .	. .	9.07	90.93
0.36	8.11	91.89	20.22	79.78	23.67	76.33	. .	. .	8.40	91.60
0.28	6.44	93.56	12.81	87.19	14.10	85.90	29.43	70.57	8.36	91.64
0.24	4.92	95.08	8.41	91.59	6.60	93.40	19.74	80 26	7.75	92.25
0.20	3.68	96.32	7.26	92.74	5.16	94.84	11.78	88.22	8.27	91.73
0.15	4.44	95.56	5.36	94.64	5.01	94.99	8.25	91.75	10.20	89.80
0.12	6.65	93.35	4.49	95.51	6.56	93.44	7.10	92.90	17.39	82.61
0.10	7.26	92.74	7.45	92.55	6.46	93.54	6.81	93.19	26.88	73.12
0.08	32.23	67.77	11.72	88.28	10.24	89.76	9.22	90.78	58.90	41.10
0.00	90.46	9.54	48.33	51.67	70.76	29.24	51.84	48.16	90.87	9.13
Middlings before sizing	23.58	76.42	26.63	73.37	15.90	84.10	12.84	87.16	13.71	86.29

TABLE X — PROPORTION OF QUARTZ AND GALENA IN PRODUCTS

NOTE. — Tailings sized and weighed and the weights computed in tons and fractions of a ton on the 100-ton basis.

SIZE. On.	Run No. 1.	Run No. 2.	Run No. 3.	Run No. 4.	Run No. 5.
mm.	Tons.	Tons.	Tons.	Tons.	Tons.
2.06	3.777	. .	. .	. .	2.003
1.63	14.713	. .	. .	. .	11.883
1.44	11.145	. .	. .	. .	9.065
1.27	8.085	. .	. .	. .	10.600
1.10	6.174	. .	. .	. .	4.294
0.97	7.322	11.860	. .	. .	4.452
0.84	5.191	16.217	. .	. .	1.489
0.68	3.350	8.821	. .	. .	0.682
0.57	2.078	5.789	. .	. .	0.405
0.45	2.501	11.639	20.635	. .	0.396
0.36	1.581	4.167	11.120	. .	0.162
0.28	1.056	3.315	10.790	0.400	0.456
0.24	0.523	0.915	2.829	2.019	0.303
0.20	0.633	2.341	3.277	12.345	0.680
0.15	0.739	1.860	3.574	11.948	1.075
0.12	1.139	1.781	4.308	9.015	0.507
0.10	0.624	1.067	1.113	6.118	0.614
0.08	0.948	1.461	2.965	9.778	0.878
0.00	1.277	1.670	2.202	8.864	0.742
Total tons . .	72.856	72.903	62.813	60.487	50.686

ANALYSES OF THE ABOVE PRODUCTS GIVING PERCENTAGES OF GALENA (PbS) AND QUARTZ (SiO_2)

SIZE.	RUN NO. 1.		RUN NO. 2.		RUN NO. 3.		RUN NO. 4.		RUN NO. 5.	
On.	Galena.	Quartz.	Galena.	Quartz.	Galena.	Quartz.	Galena.	Quartz.	Galena.	Quartz.
mm.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
2.06	0.40	99.60	. .	. .	. .	. .	. .	. .	0.00	100.00
1.63	0.40	99.60	. .	. .	. .	. .	. .	. .	0.00	100.00
1.44	0.50	99.50	. .	. .	. .	. .	. .	. .	0.00	100.00
1.27	0.20	99.80	. .	. .	. .	. .	. .	. .	0.05	99.95
1.10	0.01	99.99	. .	. .	. .	. .	. .	. .	0.02	99.98
0.97	0.02	99.98	0.02	99.98	. .	. .	. .	. .	0.02	99.98
0.84	0.00	100.00	0.01	99.99	. .	. .	. .	. .	0.03	99.97
0.68	0.00	100.00	0.00	100.00	. .	. .	. .	. .	0.01	99.99
0.57	0.00	100.00	0.00	100.00	. .	. .	. .	. .	0.08	99.92
0.45	0.00	100.00	0.00	100.00	0.00	100.00	. .	. .	0.05	99.95
0.36	0.08	99.92	0.12	99.88	0.16	99.84	. .	. .	0.68	99.32
0.28	0.12	99.88	0.16	99.84	0.64	99.36	2.95	97.05	0.80	99.20
0.24	0.69	99.31	0.26	99.74	2.03	97.97	0.41	99.59	0.74	99.26
0.20	1.24	98.76	0.80	99.20	1.19	98.81	0.69	99.31	0.82	99.18
0.15	1.45	98.55	1.40	98.60	1.49	98.51	1.00	99.00	0.76	99.24
0.12	1.82	98.18	1.89	98.11	1.65	98.35	1.26	98.74	1.16	98.84
0.10	2.88	97.12	1.69	98.31	1.60	98.40	1.76	98.24	1.71	98.29
0.08	3.43	96.57	2.60	97.40	1.51	98.49	1.49	98.51	3.00	97.00
0.00	17.50	82.50	17.85	82.15	8.55	91.45	4.28	95.72	12.17	87.83
Tailings before sizing	0.51	99.49	0.61	99.39	0.90	99.10	1.61	98.39	0.29	99.71

TABLE XI — Proportion of Quartz and Galena in Products

Note. — Slimes sized and weighed. The weights are computed in tons and parts of a ton, on the 100-ton basis.

Sizes.		Run No. 1.	Run No. 2.	Run No. 3.	Run No. 4.	Run No. 5.
Through.	On.					
mm.	mm.	Tons.	Tons.	Tons.	Tons.	Tons.
0.45	0.36	0.156	. .	. .	. .	. .
0.36	0.28	0.047	. .	. .	0.214	0.003
0.28	0.24	0.036	. .	. .	0.026	0.004
0.24	0.20	0.053	0.032	. .	0.044	0.007
0.20	0.15	0.063	0.072	0.207	0.091	0.027
0.15	0.12	0.052	0.062	0.078	0.138	0.037
0.12	0.10	0.068	0.149	0.241	1.515	0.038
0.10	0.08	0.134	0.446	1.662	1.268	0.244
0.08	0.00	0.935	2.613	4.351	9.846	0.606
Total tons		1.544	3.374	6.539	13.142	0.966

Analyses of the Above Products Giving Percentages of Galena (PbS) and Quartz (SiO_2)

Sizes.		Run No. 1.		Run No. 2.		Run No. 3.		Run No. 4.		Run No. 5.	
Through.	On.	Galena.	Quartz.	Galena.	Quartz.	Galena.	Quartz.	Galena.	Quartz.	Galena.	Quartz.
mm.	mm.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
0.45	0.36	0.00	100.00	. .	. .	. .	. .	. .	. .	. .	. .
0.36	0.28	10.20	89.80	. .	. .	. .	. .	48.54	51.46	18.30	81.70
0.28	0.24	10.00	90.00	. .	. .	. .	. .	54.55	45.45	15.40	84.60
0.24	0.20	10.81	89.19	14.04	85.96	. .	. .	40.22	59.78	11.80	88.20
0.20	0.15	12.58	87.42	7.94	92.06	45.21	54.79	37.16	62.84	8.10	91.90
0.15	0.12	19.00	81.00	7.26	92.74	21.21	78.79	28.96	71.04	6.50	93.50
0.12	0.10	24.28	75.72	7.19	92.81	17.53	82.47	9.37	90.63	5.00	95.00
0.10	0.08	27.04	72.96	5.03	94.97	8.53	91.47	6.87	93.13	6.40	93.60
0.08	0.00	28.31	71.69	10.72	89.28	11.53	88.47	8.76	91.24	19.40	80.60
Slimes before sizing		18.90	81.10	9.71	90.29	12.18	87.82	9.96	90.04	14.62	85.38

TABLE XII — RESULTS OF RUNS NOS. 6 TO 11 COMPUTED TO FULL SIZE

NOTE. — The weights of products have been computed in tons and fractions thereof.

	Run No. 6.	Run No. 7.	Run No. 8.	Run No. 9.	Run No. 10.	Run No. 11.
	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.
Concentrates	6.537	9.728	12.064	13.168	12.171	15.137
Middlings	1.647	1.901	1.694	1.602	5.310	3.170
Tailings	91.816	88.371	86.242	85.230	82.519	81.693
Slimes	0.000	0.000	0.000	0.000	0.000	0.000
Total	100.000	100.000	100.000	100.000	100.000	100.000

ANALYSES OF THE ABOVE PRODUCTS GIVING PERCENTAGES OF GALENA (PbS) AND QUARTZ (SiO_2)

	Run No. 6.		Run No. 7.		Run No. 8.		Run No. 9.		Run No. 10.		Run No. 11.	
	Galena.	Quartz.	Galena.	Quartz.	Galena.	Quartz.	Galena.	Quartz.	Galena.	Quartz.	Galena.	Quartz.
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
Concentrates	99.23	0.77	99.23	0.77	99.01	0.99	97.50	2.50	99.31	0.69	97.86	2.14
Middlings	59.67	40.33	23.10	76.90	17.00	83.00	22.60	77.40	19.97	80.03	15.35	84.65
Tailings	0.04	99.96	0.00	100.00	0.09	99.91	0.35	99.65	0.24	99.76	0.44	99.56
Slimes	..	..	..	..	..	..	..	..	..	..	..	..

TABLE XIII — RESULTS OF RUNS NOS. 12 TO 17 COMPUTED TO FULL SIZE

NOTE. — The concentrates have been sized and weighed and the weights computed in tons and fractions thereof on the 100-ton basis.

Sizes.		Run No. 12.	Run No. 13.	Run No. 14.	Run No. 15.	Run No. 16.	Run No. 17.
Through.	On.						
mm.	mm.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.
. .	2.06	0.128	. .	. .	. .	. .	. .
2.06	1.63	4.869	0.001	0.0003	. .	. .	. .
1.63	1.44	6.331	0.001	0.0003	. .	. .	. .
1.44	1.27	7.861	0.002	0.0003	. .	. .	. .
1.27	1.10	4.455	0.002	0.0002	0.0005	. .	. .
1.10	0.96	4.093	0.002	0.0003	0.0003	. .	. .
0.96	0.84	5.837	0.011	0.001	0.0003	0.0005	. .
0.84	0.68	3.674	0.036	0.002	0.0005	0.1005	0.0004
0.68	0.57	3.615	0.124	0.006	0.001	0.001	0.0004
0.57	0.45	4.347	0.730	0.054	0.005	0.004	0.0023
0.45	0.36	2.063	1.208	0.174	0.012	0.007	0.004
0.36	0.28	1.232	0.687	0.656	0.060	0.049	0.015
0.28	0.24	0.445	0.384	0.415	0.110	0.077	0.015
0.24	0.20	0.330	0.393	0.697	0.332	0.138	0.057
0.20	0.15	0 152	0.223	0.701	1.176	0.220	0.108
0.15	0.12	0.088	0.084	0.393	1.321	0.634	0.086
0.12	0.10	0.029	0.021	0.143	0.551	0.748	0.109
0.10	0.08	0.055	0.029	0.104	1.057	2.300	0.934
0.08	0.00	0.045	0.012	0.052	0.315	1.539	3.650
Total tons		49.649	3.950	3.398	4.940	5.717	4.980

ANALYSES OF THE ABOVE PRODUCTS GIVING PERCENTAGES OF GALENA (PbS) AND QUARTZ (SiO_2)

Size.	Run No. 12.		Run No. 13.		Run No. 14.		Run No. 15.		Run No. 16.		Run No. 17.	
On.	Galena.	Quartz.	Galena.	Quartz.	Galena.	Quartz.	Galena.	Quartz.	Galena.	Quartz.	Galena.	Quartz.
mm.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
2.06	100.00	0.00	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .
1.63	99.96	0.04	100.00	0.00	60.00	40.00	. .	. .	. .	. .	. .	. .
1.44	99.96	0.04	100.00	0.00	75.00	25.00	. .	. .	. .	. .	. .	. .
1.27	99.95	0.05	93.10	6.90	75.00	25.00	. .	. .	. .	. .	. .	. .
1 10	99.84	0.16	91.45	8.55	85.71	14.29	0.00	100.00	. .	. .	. .	. .
0.96	99.69	0.31	89.69	10.31	80.00	20.00	87.50	12.50	. .	. .	. .	. .
0 84	99.45	0.55	95.63	4.37	98.13	1.87	85.72	14.28	0.00	100.00	. .	. .
0.68	99.03	0.97	96.15	3.85	97.58	2.42	50.00	50.00	63.63	36.37	50.00	50.00
0.57	98.76	1.24	97.49	2.51	97.75	2.25	50.00	50.00	88.24	11.76	33.33	66.67
0.45	97.80	2.20	98.01	1.99	96.06	3.94	73.36	26.64	88.78	11.22	93.80	6.20
0.36	97.05	2.95	98.80	1.20	96.58	3.42	20.50	79.50	92.53	7.47	96.52	3.48
0.28	96.96	3.04	98.24	1.76	98.02	1.98	95.84	4.16	93.54	6.46	98.20	1.80
0.24	96.85	3.15	98.96	1.04	98.57	1.43	97.46	2.54	97.44	2.56	98.58	1.42
0.20	97.51	2.49	99.35	0.65	99.05	0.95	98.93	1.07	96.37	3.63	99.36	0.64
0.15	97.51	2.49	99.58	0.42	99.42	0.58	99.46	0.54	96.41	3.59	99.19	0.81
0.12	98.88	1.12	99.81	0.19	99.80	0.20	99.76	0.24	97.14	2.86	97.56	2.44
0 10	97.77	2.23	99.82	0.18	99.88	0.12	99.83	0.17	98.37	1.63	96.92	3 08
0 8	97.71	2.29	99.83	0.17	99.86	0.14	99.86	0.14	99.31	0.69	99.30	0.70
0.00	96.86	3.14	99.64	0.36	99.88	0.12	99.84	0.16	99.84	0.16	99.86	0.14
Concentrates before sizing	99.26	0.74	98.62	1.38	98.85	1.15	98.35	1.65	98.84	1.16	99.62	0.38

TABLE XIV — RESULTS OF RUNS NOS. 12 TO 17 COMPUTED TO FULL SIZE

NOTE. — The middlings have been sized and weighed and the weights computed in tons and fractions thereof on the 100-ton basis.

Sizes.		Run No. 12.	Run No. 13.	Run No. 14.	Run No. 15.	Run No. 16.	Run No. 17.
Through.	On.						
mm.	mm.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.
. .	2.49	0.005	. .	. .	. .	. .	. .
2.49	2.06	0.061	0.001	. .	. .	. .	. .
2.06	1.63	0.788	0.015	0.002	. .	. .	. .
1.63	1.44	0.602	0.026	0.001	. .	. .	. .
1.44	1.27	0.951	0.037	0.002	. .	. .	. .
1.27	1.10	0.676	0.014	0.002	. .	. .	. .
1.10	0.96	0.605	0.018	0.002	0.0003	. .	. .
0.96	0.84	0.758	0.078	0.005	0.0003	0.001	. .
0.84	0.68	0.473	0.120	0.011	0.002	0.001	0.001
0.68	0.57	0.263	0.194	0.033	0.003	0.003	0.001
0.57	0.45	0.234	0.494	0.092	0.020	0.011	0.003
0.45	0.36	0.042	0.188	0.133	0.031	0.025	0.004
0.36	0.28	0.030	0.089	0.236	0.139	0.064	0.075
0.28	0.24	0.015	0.014	0.048	0.093	0.070	0.080
0.24	0.20	0.011	0.011	0.068	0.250	0.213	0.281
0.20	0.15	0.004	0.003	0.020	0.146	0.290	0.809
0.15	0.12	0.004	0.002	0.005	0.076	0.188	1.013
0.12	0.10	0.001	0.001	0.001	0.015	0.051	0.531
0.10	0.08	0.004	0.001	0.001	0.028	0.060	0.909
0.08	0.00	0.007	0.001	0.001	0.025	0.057	0.555
Total tons		5.534	1.307	0.663	0.828	1.043	4.262

ANALYSES OF THE ABOVE PRODUCTS GIVING PERCENTAGES OF GALENA (PbS) AND QUARTZ (SiO_2)

Size.	Run No. 12.		Run No. 13.		Run No. 14.		Run No. 15.		Run No. 16.		Run No. 17.	
On.	Galena.	Quartz.	Galena.	Quartz.	Galena.	Quartz.	Galena.	Quartz.	Galena.	Quartz.	Galena.	Quartz.
mm.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
2.49	0.00	100.00	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .
2.06	22.34	77.66	0.00	100.00	. .	. .	. .	. .	. .	. .	. .	. .
1.63	31.80	68.20	8.84	91.16	68.18	31.82	. .	. .	. .	. .	. .	. .
1.44	25.40	74.60	10.87	89.13	55.55	44.45	. .	. .	. .	. .	. .	. .
1.27	17.70	82.30	21.33	78.67	31.82	68.18	. .	. .	. .	. .	. .	. .
1.10	7.93	92.07	28.29	71.71	41.40	58.60	. .	. .	. .	. .	. .	. .
0.96	6.73	93.27	39.39	60.61	33.33	66.67	16.67	83.33	. .	. .	. .	. .
0.84	4.04	95.96	38.92	61.08	44.45	55.55	16.67	83.33	66.67	33.33	. .	. .
0.68	3.10	96.90	29.42	70.58	42.44	57.56	59.45	40.55	23.08	76.92	64.29	35.71
0.57	2.43	97.57	25.14	74.86	37.50	62.50	61.54	38.46	66.67	33.33	52.39	47.61
0.45	3.56	96.44	31.00	69.00	38.80	61.20	62.27	37.73	79.58	20.42	75.52	24.48
0.36	5.58	94.42	47.93	52.07	38.58	61.42	59.76	40.24	47.72	52.28	83.34	16.66
0.28	9.57	90.43	49.53	50.47	32.44	67.56	33.33	66.67	28.51	71.49	28.17	71.83
0.24	16.15	83.85	46.20	53.80	28.12	71.88	18.51	81.49	11.15	88.85	10.67	89.33
0.20	22.80	77.20	52.99	47.01	26.72	73.28	18.45	81.55	5.86	94.14	4.60	95.40
0.15	27.33	72.67	71.90	28.10	32.77	67.23	16.93	83.07	4.91	95.09	2.25	97.75
0.12	95.98	4.02	88.22	11.78	42.00	58.00	23.79	76.21	6.27	93.73	3.54	96.46
0.10	96.91	3.09	92.04	7.96	60.78	39.22	41.44	58.56	11.32	88.68	5.10	94.90
0.08	97.92	2.08	91.95	8.05	74.16	25.84	79.81	20.19	40.12	59.88	11.12	88.88
0.00	98.06	1.94	96.40	3.60	6.32	93.68	98.07	1.93	90.42	9.58	82.98	17.02
Middlings before sizing .	13.85	86.15	33.95	66.05	34.43	65.57	28.90	71.10	16.25	83.75	16.28	83.72

TABLE XV — RESULTS OF RUNS NOS. 12 TO 17 COMPUTED TO FULL SIZE

NOTE. — The tailings have been sized and weighed and the weights computed in tons and fractions thereof on the 100-ton basis.

SIZE. On.	Run No. 12.	Run No. 13.	Run No. 14.	Run No. 15.	Run No. 16.	Run No. 17.
mm.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.
2.49	0.042	0.043	. .	. .	. .	. .
2.06	1.762	1.336	0.056	0.027	. .	. .
1.63	18.040	18.429	2.083	0.023	. .	0.016
1.44	10.232	21.674	4.434	0.017	0.016	0.011
1.27	8.176	20.207	11.129	0.030	0.016	0.011
1.10	2.828	11.066	9.834	0.071	0.016	0.011
0.96	1.590	7.877	8.167	0.185	0.021	0.022
0.84	1.457	7.835	13.670	0.780	0.026	0.016
0.68	0.281	2.676	13.131	1.843	0.047	0.033
0.57	0.178	2.098	11.080	7.316	0.165	0.044
0.45	0.103	1.122	14.410	21.851	2.381	1.945
0.36	0.021	0.121	4.532	20.371	5.709	5.423
0.28	0.019	0.097	2.604	30.530	34.072	31.480
0.24	0.015	0.038	0.437	5.486	17.393	17.182
0.20	0.017	0.024	0.220	4.473	18.163	19.917
0.15	0.012	0.019	0.087	0.790	10.150	10.175
0.12	0.015	0.014	0.033	0.240	3.129	2.845
0.10	0.002	0.009	0.010	0.084	1.249	0.911
0.08	0.010	0.029	0.010	0.071	0.580	0.544
0.00	0.017	0.029	0.012	0.044	0.169	0.172
Total tons . .	44.817	94.743	95.939	94.232	93.240	90.758

ANALYSES OF THE ABOVE PRODUCTS, GIVING PERCENTAGES OF GALENA (PbS) AND QUARTZ (SiO_2)

SIZE.	RUN NO. 12.		RUN NO. 13.		RUN NO. 14.		RUN NO. 15.		RUN NO. 16.		RUN NO. 17.	
On.	Galena.	Quartz.	Galena.	Quartz.	Galena.	Quartz.	Galena.	Quartz.	Galena.	Quartz.	Galena.	Quartz.
mm.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
2.49	0.00	100.00	0.00	100.00	. .	. .	. .	. .	. .	. .	. .	. .
2.06	0.00	100.00	0.00	100.00	0.00	100.00	0.00	100.00	. .	. .	. .	. .
1.63	0.00	100.00	0.08	99.92	0.00	100.00	0.00	100.00	. .	. .	. .	. .
1.44	0.52	99.48	0.07	99.93	0.09	99.91	0.00	100.00	0.00	100.00	0.00	100.00
1.27	0.20	99.80	0.48	99.52	0.06	99.94	0.00	100.00	0.00	100.00	. .	. .
1.10	0.38	99.62	0.09	99.91	0.06	99.94	0.00	100.00	0.00	100.00	. .	. .
0.96	0.67	99.33	0.18	99.82	0.03	99.97	0.00	100.00	0.00	100.00	. .	. .
0.84	0.74	99.26	0.18	99.82	0.03	99.97	0.00	100.00	0.00	100.00	. .	. .
0.68	0.76	99.24	0.54	99.46	0.02	99.98	0.00	100.00	1.10	98.90	. .	. .
0.57	1.20	98.80	1.16	98.84	0.02	99.98	0.00	100.00	0.32	99.68	0.00	100.00
0.45	1.03	98.97	6.04	93.96	0.10	99.90	0.17	99.83	0.86	99.14	1.36	98.64
0.36	1.28	98.72	16.00	84.00	0.84	99.16	0.23	99.77	0.45	99.55	0.69	99.31
0.28	7.08	92.92	33.05	66.95	2.08	97.92	0.98	99.02	0.17	99.83	0.34	99.66
0.24	9.22	90.78	27.60	72.40	3.88	96.12	0.27	99.73	0.30	99.70	0.58	99.42
0.20	5.64	94.36	19.00	81.00	5.21	94.79	0.43	99.57	0.35	99.65	0.55	99.45
0.15	5.90	94.10	13.32	86.68	7.73	92.27	3.30	96.70	0.44	99.56	0.54	99.46
0.12	7.50	92.50	15.30	84.70	9.59	90.41	8.97	91.03	0.87	99.13	1.01	98.99
0.10	5.40	94.60	40.40	59.60	72.79	27.21	17.32	82.68	1.83	98.17	2.07	97.93
0.08	28.38	71.62	55.55	44.45	21.43	78.57	26.55	73.45	7.04	92.96	7.38	92.62
0.00	85.93	14.07	87.00	13.00	68.68	31.32	68.32	31.68	42.36	57.64	44.28	55.72
Tailings before sizing	0.29	99.71	0.36	99.64	0.20	99.80	0.55	99.45	0.46	99.54	0.66	99.34

Having laid out our argument in this way, it now remains for us to compare by means of this diagram runs Nos. 1 to 5, 6 to 11, and 12 to 17, and to see why it is that runs Nos. 6 to 11 and Nos. 12 to 17 are so much better than runs Nos. 1 to 5. Runs Nos. 1 to 5 take the products just as they are shown in Figure 4, and give galena, *C*, *D*, *E*, *F*, in the concentrates contaminated by quartz (*N*). See the heaping up of the quartz a little below the middle size in Table VIII, and the middlings that give quartz, *K*, *L*, and *M*, contaminated by galena, *A*, *B*, *C*, and *G*. See the heaping up of galena among the large grains and among the small grains in Table IX, and the tailings have in them the quartz, *I*, *J*, and *O*, contaminated by galena, *G*. See the heaping up of galena in the fine sizes in Table X. Runs Nos. 6 to 11, on the other hand, have put together on the coarse table, quartz, *I*, and galena, *A*, which have nothing whatever to do with one another (see Table XII), and therefore make almost 100 per cent. of galena in the concentrates, and almost 100 per cent. of quartz in the tailings. The little accidental middling product, simply being the dividing line between the two products, goes back on the table and disappears. On the second table we treat quartz, *J*, and galena, *B*, with the same result. On the third table we treat quartz, *K*, and galena, *C*, with the same result; on the fourth table quartz, *L*, and galena, *D;* on the fifth table quartz, *M*, and galena, *E;* on the sixth table quartz, *N*, and galena, *F*. There seems no reason logically why these should not turn out 100 per cent. of galena in the concentrates and 100 per cent. of quartz in the tailings. The probable reason why we did not obtain those figures was that the accidental flat scales and the fine abrasions of galena went where they should not.

Going to the third set of runs, Nos. 12 to 17, we need to bring in an ideal picture of the products of a classifier by means of Figure 5. Suppose, for example, that we drop into a tall tube of water grains of quartz ranging from our maximum size down to zero, and grains of galena in the same way, and that these grains are of approximately the same shape, then the rate of settling of these grains may be stated in the following terms: The larger grains of a single mineral will settle faster than the smaller grains; and when we compare the two gravities of quartz and galena, the higher gravity will settle faster than the lower gravity for the same size. So definite is this law, that if we look for equal-settling particles we shall find that the grain of quartz which is equal-settling with the grain of galena is about three

or four times the diameter of the grain of galena. See settling ratios in Table III. We may, therefore, construct the ideal diagram, Figure 5, and we can draw a set of horizontal lines across it, putting the equal-settling grains together, ranging from the heavier grains of the first spigot in the lower part of the diagram up to the lighter grains of the finer spigot at the upper part of the diagram. We see then

FIG. 5.—IDEAL SKETCH OF CLASSIFIER-PRODUCT

that spigot 1 contains a large amount of galena ranging from the coarsest size down to one-quarter the diameter of the coarsest quartz, and that the quartz is almost all in the coarse sizes. See spigot 1, Table III. This is exactly what we found in our run No. 12. See the heaping up of galena in the large sizes in Table XIII.

Spigot 2 has small galena and large quartz, but both are a little smaller than those in spigot 1. Spigot 3, again, has small galena and larger quartz, but a little smaller than spigot 2, and so on up the scale

with spigot 4, spigot 5, and spigot 6. See the heaping up of galena in smaller sizes, Table XIII, and of quartz in larger sizes in Table XV.

Looking at our diagram, Figure 4, to see what will happen when these several spigots are put upon the table, we shall find that run No. 12 receives galena, *A, B, C, D, E, F,* and *G,* and quartz, *I.* Logically these have nothing to do with one another, and therefore should make for perfect separation. Spigot 2 fed in run No. 13 would have quartz, *J,* and galena, F_2. Spigot 3 would have quartz, *K,* and galena, F_3, and so on. Spigots 4, 5, and 6 could work their way up, having quartz always larger, and therefore belonging at a lower place on the table, and galena of smaller diameter belonging at a higher place on the table, making for clean separation of concentrates and tailings, with a middling product that can go directly back on the table and disappear. In proof of this, see points of heaping up of galena and quartz in Tables XIII and XV.

In the light of Figure 4, comparing runs 12 to 17 with runs 6 to 11 we see that the natural lines for quartz and galena are farther apart for the classified products than for the sized products. For example, in run 12 the galena lines *A* to *F* average farther from the quartz *I* than does the galena *A* of run 6. Again, in run 13 the galena *F* is farther from quartz *J* than is the galena *B* from quartz *J* in run 7. In like manner we may compare classified runs 14, 15, 16, and 17 with sized runs 8, 9, 10, and 11.

This demonstrates that with perfect classification the work will be better done on the Wilfley table than with sizing, and it also shows that with much middle weight mineral or included grains a good classifier will probably be more efficient than screens.

Conclusions

1. The natural product as feed for a Wilfley table is completely outclassed and surpassed by sized-product feed and by classifier-product feed.

2. While the sized-product feed, as shown in Table VII, appears to have done better work than the classifier-product feed, if we give full weight to the great performance of run No. 12, we can agree that this has fully offset the slight falling off of runs Nos. 13 to 17, and that the classifier-feed work is fully up to the sized-feed work on the Wilfley table, and with a perfect classifier the work will be better done than with screens.

TENSION TESTS OF STEEL ANGLES WITH VARIOUS TYPES OF END-CONNECTION[1]

By FRANK P. McKIBBEN

THE tests which form the subject of this paper were made upon thirty-three steel angles, such as are used for tension members in riveted framed structures. They are a continuation of a series made at the Massachusetts Institute of Technology in 1906 (*Engineering News*, July 5, 1906, p. 14; TECHNOLOGY QUARTERLY, 19, No. 3, pp. 306–313). This series of tests (begun last year and not yet completed) has been undertaken with a view of studying the following points:

(1) The ultimate strength of the angles in tension.

(2) The value of a lug in transmitting stress from the outstanding leg of the main angle into the hitch plate.

(3) The relative strength of angles where the gauge line for rivets and where the centre of gravity line, respectively, pass through the centre of the pull.

(4) The effect of the position of the rivets connecting the main angles to the hitch plates.

(5) The relative strength of single angles and angles riveted together to form pairs.

(6) The effect upon the strength of the specimen of the different methods of holding the specimen in the testing machine.

In the series tested this year there are three specimens of each of ten different types, also three specimens which differ from one another and from one of the ten types only slightly. This makes thirty-three angles in all. These are shown in detail in Figure 1. Each of the main angles, 5 feet 4 inches in length, is riveted at each end to a hitch plate.

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[1] A paper read before the American Society for Testing Materials at Atlantic City, N. J., June 22, 1907. Reprinted from Engineering News, Aug. 22, 1907, 58, No. 8, pp. 190–192.

The description of the different types tested is as follows:

A_3: One $3\frac{1}{2} \times 3 \times \frac{3}{8}$ inch angle, connected at each end by six rivets, three in each leg, with lugs; and with the gauge line passing through the centre of pull.

A_4: same as A_3, except with centre of gravity line, in plan, passing through centre of pull.

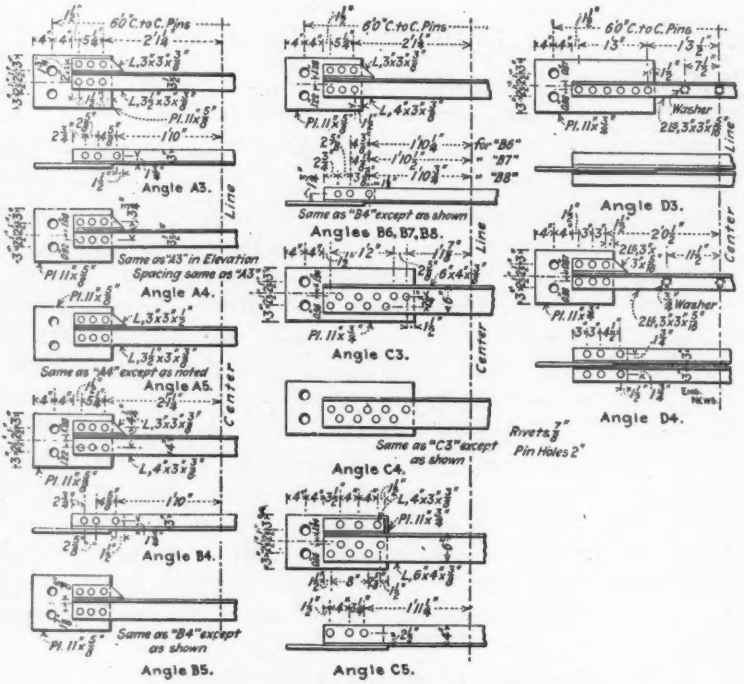

FIG. 1.—TEST SPECIMENS USED IN 1907 TESTS OF STEEL ANGLES

A_5: same as A_4, but with thicker lug angles.

B_4: similar to A_4, but with $4 \times 3 \times \frac{3}{8}$ inch main angles.

B_5: similar to B_4, but with centre of pull passing in plan $\frac{5}{8}$ inch from back of vertical leg.

B_6, B_7, B_8: same as B_4, but with staggers between the two inner rivets decreasing successively by $\frac{1}{4}$ inch.

C_3: One $6 \times 4 \times \frac{3}{8}$ inch angle connected to each hitch plate by nine rivets staggered in two rows in the 6-inch leg, but with both inner

rivets on the gauge line nearest the back of the angle. Centre of gravity line passes through centre of pull.

C_4: same as C_3, except that the two inner rivets are staggered instead of on the same gauge line.

C_5: similar to C_4, but with lugs; six rivets in 6-inch leg and three rivets in 4-inch leg at each plate.

D_3: Two $3 \times 3 \times \frac{3}{8}$ inch angles, one on each side of the hitch plate, and connected without lugs to each plate by six rivets all in one row. The centre of gravity line passes through centre of pull.

D_4: similar to D_3, but with lugs; each main angle is connected at either end with three rivets in each leg.

Improvements upon the types of connections used in the 1906 series of tests were attempted in the following ways: (1) By increasing the stagger between the two inner rivets, in cases where there were rivets in both legs of the angle, until the minimum net zigzag area of the angle through two rivets was at least equal to the net right section. (2) By placing the two inner rivets on the inner gauge line in specimens having two rows of rivets in the leg connecting with the hitch plate. (3) By applying the pull to the specimen through the centre of gravity line of the angle in plan. (4) By using thicker lug angles.

The connections of the angles to the hitch plates were so designed as to ensure failure in the angles rather than in the rivets or connecting plates. The hitch plate at each end of each specimen was provided with two 2-inch holes, by means of which it was pinned between two holding plates, which in turn were connected by a single pin to a third plate gripped by the testing machine. (*Engineering News*, July 5, 1906, page 14; TECHNOLOGY QUARTERLY, *l. c.*, Figure 2, page 30.) It should be borne in mind that the holding device is a flexible joint, and is not the rigid connection more commonly found in structures in which angles are used as tension members. The method of holding the ends has an important bearing on the strength of the angles, and the presence of this flexible joint should not be lost sight of in studying the results of the tests thus far made. The writer hopes to make further tests in which a rigid connection is to be used.

Table I gives the results of the physical tests of small tensile test bars which were cut from the long angles, out of which were taken the main angles of the specimens tested this year. In most cases three such test bars were taken from each long angle, but in two cases only two bars were secured from each long angle. On all of these test

pieces the yield point was determined by the drop of the beam and also by measurement with dividers.

TABLE I — PHYSICAL PROPERTIES OF SMALL TEST BARS CUT FROM STEEL ANGLES USED IN 1907 TESTS

Test piece.	Yield point.	Ultimate strength.	Elongation.	Reduction of area.
	Lbs. per sq. in.	Lbs. per sq. in.	Per cent. in 8 in.	Per cent.
AA3, AA4	35,500	57,900	29.1	57.0
	35,500	57,800	28.6	53.3
	35,300	57,600	28.6	54.7
Mean	35,400	57,800	28.8	55.0
AA5	36,100	56,500	29.6	56.3
	34,700	56,600	29.0	54.5
	34,700	56,500	28.9	49.7
Mean	35,200	56,500	29.2	53.5
BB4, BB5, BB7	35,000	53,500	29.2	58.6
	34,300	53,400	31.9	59.3
	35,100	54,000	30.9	58.2
Mean	34,800	53,600	30.7	58.7
BB6, BB8	35,400	59,500	27.0	50.4
	33,700	60,000	28.0	48.6
	36,900	59,900	27.4	54.4
Mean	35,300	59,800	27.5	51.1
CC3, CC4, CC5	36,900	59,800	31.3	55.2
	37,600	59,300	27.1	57.1
	38,400	59,600	27.9	54.7
Mean	37,600	59,600	28.8	55.7
DD3	39,000	60,200	25.9	49.3
	38,900	59,600	26.8	51.2
Mean	39,000	59,900	26.4	50.3
DD4	38,400	58,800	30.3	50.8
	39,100	58,800	28.5	56.5
Mean	38,800	58,800	29.4	53.7

NOTE. — The test pieces were approximately ⅜ square inch in cross-section (0.455 to 0.573 square inch).

In Figure 2 are shown diagrammatically the outlines of the fractures, all of which occurred in the main angles. The numbers on the sketches indicate the sequence of the ruptures. With the exception of specimen 57, made of two $3 \times 3 \times \frac{5}{16}$ inch angles, failure occurred at one of the inner rivets which connects the main angle to the hitch plate, that is, the connecting rivet which lies nearest to the centre of the specimen. In the case of specimen 57 one of the angles failed at the inner connecting rivet, but the other angle failed at the first tack rivet 8 inches from the inner rivet. In every case the fracture started at a rivet. In the majority of cases of specimens having lugs failure occurred on a zigzag section passing through rivets in the horizontal and in the vertical legs. This was the case, even though the minimum net zigzag section was slightly larger than the net right section, as, for example, specimens 31, 32, 33. In some of the specimens having

the two net sections just mentioned nearly equal, for instance specimens 35 and 37, the fracture really occurred on the zigzag section, but it also started on the right section. Failure occurred on the right section in some cases. In many specimens the angle failed by shearing on the diagonal section between the inner rivets in the horizontal and in the vertical legs after the metal between these rivets and the outer edges of the legs had been broken. The fractures were all silky. In specimen 50 a slight flaw was detected after failure at the inner rivet

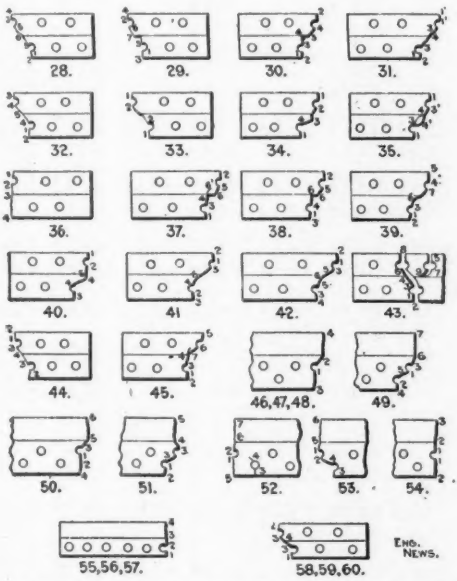

FIG. 2.— SKETCHES OF STEEL ANGLES HAVING VARIOUS TYPES OF END-CONNECTION

in the leg attached to the plate. The specimens made of two angles failed more suddenly than those made of one.

Table II is a summary of the tests of the specimens. Nos. 1 to 27, inclusive, are those tested in 1906 and previously published, and Nos. 28 to 60, inclusive, are those tested this year. The figures in the columns headed "Per Cent. of Ultimate Strength Developed" are obtained by dividing the strength per square inch in the specimen by the ultimate strength per square inch of the small test bars and multiplying by 100 to reduce to a percentage basis. Net areas have been

TABLE II — Summary of Tension Tests of Steel Angles, 1906 and 1907

1906 Tests.			Areas in Square Inches.					Total breaking load in pounds.	Breaking Loads in Pounds per Square Inch.					Per Cent. of Ultimate Strength Developed.*				
Type.	No. of specimen.	Nominal dimensions.	Actual gross.	Net right. 13/16" holes.	Net right. 1" holes.	Least net zigzag. 13/16" holes.	Least net zigzag. 1" holes.		Actual gross area.	Net right section. 13/16" holes.	Net right section. 1" holes.	Least net zigzag. 13/16" holes.	Least net zigzag. 1" holes.	Actual gross area.	Net right section. 13/16" holes.	Net right section. 1" holes.	Least net zigzag. 13/16" holes.	Least net zigzag. 1" holes.
A1	1	3½" × 3" × ⅜"	2.29	1.95	1.93	. .	. .	89,500	39,100	45,900	46,400	. .	. .	65.9	77.4	78.3	. .	. .
	2		2.32	1.97	1.95	. .	. .	96,100	41,400	48,800	49,300	. .	. .	69.8	82.3	83.2	. .	. .
	3		2.35	2.00	1.98	. .	. .	95,200	40 500	47,600	48,100	. .	. .	68.3	80.3	81.1	. .	. .
	Mean		2.32	1.97	1.95	. .	. .	93,600	40,300	47,400	47,900	. .	. .	68.0	80.0	80.9	. .	. .
A2	4	3½" × 3" × ⅜"	2.28	1.94	1.92	1.67	1.63	84,600	37,100	43,600	44,000	50,600	51,900	62.5	73.6*	74.3	85.4	87.6
	5		2.31	1.97	1.94	1.69	1.64	88,6 0	38,300	45,000	45,600	52,400	54 000	64.5	76.0	77.0	88.4	91.1
	6		2.27	1.93	1.91	1.66	1.61	91 200	40,200	47,200	47,700	54,900	56,600	67.8	79.6	80.5	92.7	95.5
	Mean		2.29	1.95	1.92	1.67	1.63	88,100	38,500	45,300	45,800	52,600	54,200	64.9	76.4	77.3	88.8	91.4
B1	7	4" × 3" × ⅜"	2.43	2.10	2.07	. .	. .	87,000	35,900	40 500	41,100	. .	. .	64.8	75.0	76.1	. .	. .
	8		2.42	2.09	2.06	. .	. .	84 000	34,700	40,200	40,800	. .	. .	64.2	74.5	75.6	. .	. .
	9		2.50	2.15	2.13	. .	. .	85,600	34,200	39,800	40,200	. .	. .	63.3	73.7	74.5	. .	. .
	Mean		2.45	2.11	2.09	. .	. .	84,900	34,600	40,200	40,700	. .	. .	64.1	74.4	75.4	. .	. .
B2	10	4" × 3" × ⅜"	2.42	2.09	2.06	1.82	1.76	83,500	34,500	39,900	40,500	45,900	47,400	63.9	73.9	75.0	85.0	87.8
	11		2.43	2.09	2.07	1.81	1.76	85,100	35,000	40,700	41,100	47,000	48,400	64.8	75.4	76.1	87.1	89.7
	12		2.45	2.11	2.08	1.86	1.81	84,100	34,300	39,900	40,400	45,200	46,500	63.5	73.9	74.8	83.7	86.1
	Mean		2.43	2.10	2.07	1.83	1.78	81 200	34,600	40,200	40,700	46,000	47,400	64.1	74.4	75.3	85.3	87.9
B3	13	4" × 3" × ⅜"	2.40	2.07	2.04	. .	. .	88,600	36,900	42 800	43,400	. .	. .	68.3	79.3	80.3	. .	. .
	14		2.42	2.09	2.06	. .	. .	90,400	37,300	43,200	43,800	. .	. .	69.0	80.0	81.1	. .	. .
	15		2.41	2.07	2.05	. .	. .	91,000	37,800	44,000	44,400	. .	. .	70.0	81.5	82.2	. .	. .
	Mean		2.41	2.08	2.05	. .	. .	90,000	37,300	43,300	43,900	. .	. .	69.1	80.3	81.2	. .	. .
C1	16	6" × 4" × ⅜"	3.53	3.17	3.15	3.11	3.06	131,000	37,100	41,300	41,600	42,100	42,800	71.9	80.0	80.7	81.6	82.9
	17		3.54	3.18	3.16	3.12	3.07	125,700	35,500	39,500	39,700	40,300	40,900	68.8	76.6	76.9	78.1	79.3
	18		3.50	3.14	3.12	3.07	3.03	128,200	36,600	40,800	41,100	41,800	42,300	70.9	79.1	79.7	81.0	82.0
	Mean		3.52	3.16	3.14	3.10	3.05	128,300	36,400	40,500	40,800	41,400	42,000	70.5	78.6	79.1	80.2	81.4
C2	19	6" × 4" × ⅜"	3.50	3.20	3.17	2.90	2.83	131,500	37,600	41,100	41,500	45,300	46,500	72.9	79.7	80.4	87.8	90.1
	20		3.50	3.19	3.17	2.89	2.82	130 200	37,200	40,800	41,100	45,000	46,200	72.1	79.1	79.7	87.2	89.5
	21		3.50	3.19	3.17	2.89	2.82	131,900	37,700	41,300	41,600	45,600	46,800	73.0	80.1	80.7	88.4	90.7
	Mean		3.50	3.19	3.17	2.89	2.82	131,200	37,500	41,100	41,400	45,300	46,500	72.7	79.6	80.3	87.8	90.1
D1	22	2-5" × ⅜" × ⅝"	3.44	2.88	2.84	. .	. .	134,100	39,000	46,600	47,200	. .	. .	64.0	76.4	77.4	. .	. .
	23		3.43	2.87	2.83	. .	. .	136,500	39,8 0	47,600	48,200	. .	. .	65.2	78.1	79.0	. .	. .
	24		3.50	2.92	2.88	. .	. .	139,100	39,800	47,700	48,300	. .	. .	65.2	78.2	79.2	. .	. .
	Mean		3.46	2.89	2.85	. .	. .	136,600	39,500	47,300	47,900	. .	. .	64.8	77.6	78.5	. .	. .
D2	25	2-5" × 3" × ⅝"	3.43	2.87	2.83	2.48	2.41	137,900	40,100	48,000	48,700	55,600	57,200	65.7	78.7	79.8	91.2	93.8
	26		3.43	2.87	2.83	2.47	2.40	140,400	40,9.0	48,900	49,600	56,800	58,500	67.0	80.2	81.3	93.1	95.9
	27		3.42	2.86	2.82	2.46	2.39	138,800	40,600	48,500	49,200	56,400	58,100	66.6	79.5	80.6	92.5	95.2
	Mean		3.43	2.87	2.83	2.47	2.40	139,000	40,500	48,500	49,200	56,3 0	57,900	66.4	79.5	80.6	92.3	95.0

TABLE II — *Continued*

		1907 Tests.																
A3	28	3½″ × 3″ × ⅜″	2.24	1.91	1.89	1.96	1.92	94,400	42,100	49,400	49,900	48,100	49,200	72.9	85.5	86.5	83.2	85.1
	29		2.26	1.93	1.91	1.98	1.94	96,900	42,900	50,200	50,700	48,900	49,900	74.3	86.9	87.8	84.6	86 3
	30		2.25	1.92	1.90	1.98	1.93	98,200	43,600	51,100	51,700	49.600	50,900	75.5	88.5	89.5	85.9	88 0
	Mean		2.25	1.92	1.90	1.97	1.93	96,500	42,900	50,200	50,800	48,900	50,000	74.2	87.0	87.9	84.6	86.5
A4	31	3½″ × 3″ × ⅜″	2.27	1.93	1.91	1.99	1.94	99,600	43,900	51,600	52,100	50,000	51,400	76.0	89.3	90.2	86.5	89 0
	32		2.23	1.91	1.89	1.96	1.91	97,300	43,600	51,000	51,500	49,600	51,000	75.5	88.3	89.1	85.9	88.2
	33		2.25	1.92	1.90	1.97	1.93	99,200	44,100	51,700	52,200	50,400	51,400	76.3	89.5	90.4	87.1	89.0
	Mean		2.25	1.92	1.90	1.97	1.93	98,700	43,900	51,400	51,900	50,000	51,300	75.9	89.0	89.9	86.5	88.7
A5	34	3½″ × 3″ × ⅜″	2.27	1.93	1.91	1.98	1.94	97,600	43,000	50,600	51,100	49,300	50,300	76.1	89.6	90.5	87.3	89.1
	35		2.28	1.95	1.93	2.00	1.96	98,500	43,200	50,500	51,000	49,300	50,300	76.5	89.5	90.3	87.3	89.1
	36		2.26	1.92	1.90	1.98	1.94	97,900	43,300	51,000	51,500	49,500	5 ,500	76.6	90.3	91.2	87.6	89.4
	Mean		2.27	1.93	1.91	1.99	1.95	98,000	43,200	50,700	51,200	49,400	50,400	76.4	89.8	90.7	87.4	89.2
B4	37	4″ × 3″ × ⅜″	2.41	2.08	2.06	2.10	2.06	100,400	41,700	48,300	48,800	47,900	48,800	77.9	90.1	91.0	89.3	91 0
	38		2.40	2.06	2.04	2.08	2.04	98,300	41,000	47,700	48.200	47,200	48,200	76.5	89.0	90.0	88.0	90.0
	39		2.43	2.10	2.08	2.12	2.07	101,400	41,700	48,300	48.800	47,800	49,000	77.9	90.1	91.0	89 2	91.5
	Mean		2.41	2.08	2.06	2.10	2.06	100,000	41,500	48,100	48,600	47,600	48,700	77.4	89.7	90.7	88.8	90.8
B5	40	4″ × 3″ × ⅜″	2.39	2.06	2.04	2.09	2.04	100,500	42,000	48,800	49,300	48,100	49,300	78.4	91.0	92.0	89.8	91.9
	41		2.41	2.08	2.06	2.11	2.06	103,500	42,900	49,800	50,200	49,000	50,200	80.1	92.9	93.7	91.5	93.7
	42		2.48	2.14	2.12	2.16	2.12	104.500	42,100	48,800	49,300	48,300	49,300	78 6	91.0	92.0	90 1	91 9
	Mean		2.43	2.09	2.07	2.12	2.07	102,800	42,300	49,100	49,600	48,500	49,600	79.0	91.6	92.6	90.5	92.5
B6	43	4″ × 3″ × ⅜″	2.39	2.06	2.04	2.03	1.99	100,600	42,000	48,900	49,300	49,500	50,500	70.3	81.8	82.5	82.8	84.4
B7	44		2.44	2.10	2.08	2.03	1.98	103,500	42,400	49,300	49,800	51,000	52,300	79.1	92.0	92.9	95.1	97.6
B8	45		2.40	2.06	2.04	1.95	1.90	101,800	42,400	49,400	49,900	52,200	53,500	70.9	82.6	83.5	87.3	89.5
C3	46	6″ × 4″ × ⅜″	3.60	3.24	3.22	. .	. .	154,600	42,900	47,700	48,000	. .	. .	72.0	80.0	80.5	. .	. .
	47		3.56	3.20	3.18	. .	. .	150,600	42,300	47,000	47,300	. .	. .	71.0	78.8	79.4	. .	. .
	48		3.58	3.22	3.20	. .	. .	153,300	42,800	47,600	47,900	. .	. .	71.8	79.9	80.3	. .	. .
	Mean		3.58	3.22	3.20	. .	. .	152,800	47,700	47,400	47,700	. .	. .	71.6	79.6	80.1	. .	. .
C4	49	6″ × 4″ × ⅜″	3.56	3.21	3.18	3.31	3.26	150,600	42,300	46,900	47,300	45,500	46,200	71.0	78.6	79.4	76.3	77.5
	50		3.54	3.19	3.16	3.29	3.24	144,100	40,700	45,200	45,600	43,800	44,500	68.3	75.9	76.5	73.5	74.6
	51		3.54	3.19	3.17	3.29	3.25	152,200	43,000	47,700	48,000	46,300	46,800	72.1	80.0	80.5	77.6	78.5
	Mean		3.55	3.20	3.17	3.30	3.25	149,000	42,000	46,600	47,000	45,200	45,800	70.5	78.2	78.8	75.8	76.9
C5	52	6″ × 4″ × ⅜″	3.54	3.18	3.16	3 20	3.16	143,500	40,500	45,100	45,400	44,800	45,400	68.0	75.7	76.1	75.1	76.1
	53		3.53	3.18	3.16	3.20	3.15	148,000	41,900	46,500	46,800	46,300	47,000	70.2	78.0	78.5	77.6	78.9
	54		3.51	3.16	3.14	3.18	3.13	146,400	41,800	46,300	46,600	46,000	46,700	70.1	77.7	78.2	77.1	78.5
	Mean		3.53	3.17	3.15	3.19	3.15	146,000	41,400	46,000	46,300	45,700	46,400	69.4	77.1	77.6	76.6	77.8
D3	55	2-3″ × 3″ × ⅛″	3.43	2.88	2.84	. .	. .	140,000	40,800	48,600	49,300	. .	. .	68 1	81.2	82.4	. .	. .
	56		3.39	2.83	2.79	. .	. .	140,700	41,500	49,700	50,400	. .	. .	69 3	82.9	84.2	. .	. .
	57		3.39	2.83	2.79	. .	. .	140,600	41,500	49,600	50,300	. .	. .	69.3	82.9	84 0	. .	. .
	Mean		3.40	2.85	2.81	. .	. .	140,400*	41,300	49,300	50,000	. .	. .	68.9	82.3	83.5	. .	. .
D4	58	2-3″ × 3″ × ⅛″	3.38	2.83	2.80	2 87	2.80	135,600	40,100	47,900	48,400	47,200	48,400	68.2	81.5	82.3	80.3	82.3
	59		3.34	2.79	2.76	2 84	2.76	134,800	40,300	48,300	48,800	47,500	48,800	68.5	82.1	83.0	80.8	83.0
	60		3.37	2.82	2.78	2 87	2.78	130,000	38,600	46,100	46,800	45,300	46,800	65.5	78.5	79.5	77.0	79.6
	Mean		3.36	2.81	2.78	2.86	2.78	133,500	39,700	47,400	48,000	46,700	48,000	67.4	80.7	81.6	79.4	81.6

* Figures of five preceding columns compared with results of test bars.

computed under the assumption that the holes are $\frac{15}{16}$ inch in diameter and again that they are 1 inch in diameter. The least zigzag sections have been computed by assuming the angles to be developed about the corners and taking the net areas on a section passing from the edges of the legs to the centres of the inner rivet holes, then diagonally between centres of rivets. In the results published last year the net areas given were not the least zigzag areas, but were those computed on sections which approximated the fractured sections. In the accompanying table last year's tests have been revised, so that the net zigzag areas shown are the least that can be obtained for those tests.

In studying the results of these tests it should be remembered that the ends of the specimens are not held rigidly in the testing machine and that there are a comparatively small number of angles of any one kind. However, the results, so far as they go, should be studied with a view of determining the most efficient connection. The efficiency of a specimen may be based upon its gross area or upon its minimum net area. This latter area may be either that of a right section or that of a zigzag section. On the whole, it seems most reasonable to base the efficiency on the gross area of the angle, so that if we have a series of angles of the same size — gross cross-section and quality, but with different end-connection — that connection is the most efficient which will allow the angle to carry the maximum load.

Basing our study, therefore, on the stress per square inch of gross area of the angles, and considering all of the angles of a given size, the tests seem to show that for the $3\frac{1}{2} \times 3 \times \frac{3}{8}$ inch angles the greatest efficiency, 76.4 per cent., occurs with those angles, with lugs, having the pull passing through the centre of gravity of the angle in plan. Inasmuch as the efficiencies of the specimens A_3, A_4, and A_5 are about the same, and are much greater than those of A_1 and A_2 tested last year, it appears that this gain in efficiency is due largely to the increased stagger of the inner rivets in the two legs of the angles. The importance of this stagger is seen by comparing A_3 and A_2. Of the specimens A_3, A_4, and A_5, the last two, both of which have the centre of pull coinciding with the centre of gravity instead of with the gauge line, show the greatest efficiency.

For the $4 \times 3 \times \frac{3}{8}$ inch angles the greatest efficiency is obtained from B_4 and B_5, which make a much better showing than the angles of the same size tested last year. The advantage of having the large stagger between the inner rivets of the two legs will be noticed by

comparing an efficiency of 77.4 per cent. for B_4 with an average of 73.4 per cent. for B_6, B_7, and B_8. In B_4 the average net right section is less than the average net zigzag section, while for B_6, B_7, and B_8 the reverse is true.

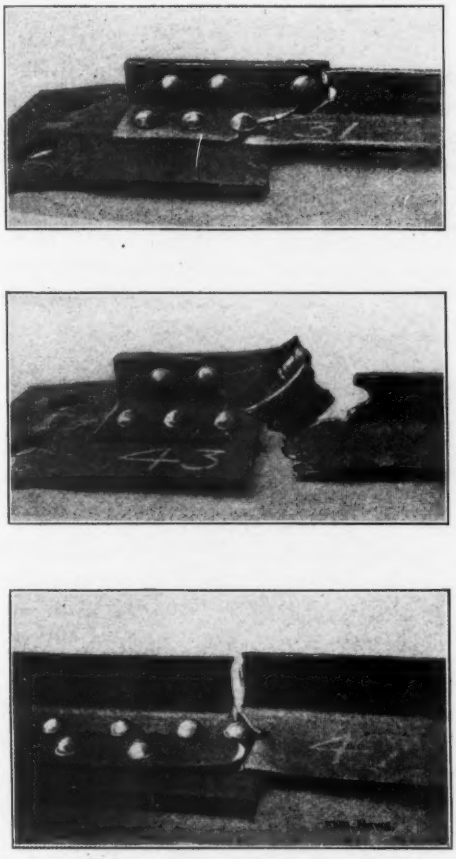

FIG. 3.—THREE TYPICAL FRACTURES
Specimens 31 (A4), 43 (B6), and 47 (C3)

For the $6 \times 4 \times \frac{3}{8}$ inch angles the greatest efficiency for this year's tests is shown for C_3, which has no lugs, has the first two rivets on the same gauge line, and has the line of pull through the centre of gravity of the specimen. However, a slightly better showing was made

by C_2 of last year's series. C_2 had lugs and had the centre of pull passing through the inner gauge line of the main angle.

Of the specimens composed of two $3 \times 3 \times \frac{5}{16}$ inch angles the greatest efficiency is shown by this year's tests with 68.9 per cent. for D_3, which has no lugs and has the centre of pull passing through the centre of gravity of the angles.

Acknowledgment is due to the American Bridge Company, of New York, for the specimens; to Messrs. C. T. Bartlett and H. B. Orcutt, of the class of 1906, to Mr. A. F. Holmes, Instructor, and to Messrs. F. W. Morrill and H. B. Hastings, of the class of 1907, for the care and thoroughness with which they did the work in the laboratory.

BOOK REVIEWS

Coaling at Sea[1]

The Lidgerwood Company has issued a trade publication of unusual interest, especially in view of the present voyage of the battleship fleet to the Pacific Ocean. It is a description, profusely illustrated, of apparatus for transferring coal from collieries to battleships, or from larger vessels to the smaller torpedo craft.

The pamphlet may be had free upon application to the publisher.

Mining and Geology, Western Australia[2]

The Bulletins of the Geological Survey of Western Australia recently issued continue the description of the geology of that country, with special reference to the mining industry.

Bulletin 23 is the third report on the geological features and mineral resources of the Pilbara gold field, by A. G. Maitland. It takes up in detail six of the individual mining centres, giving a history, an account of the general geology, and a description of the ore deposits of each. These sections are followed by a general summary of the general geology and economic geology of the region.

Bulletin 24 is a detailed account of the Mt. Margaret gold field, by Charles G. Gibson, and like the previous bulletin takes up in detail the general geology, mines, and the statistics of the various portions of this industry.

Bulletin 25 is by R. L. Jack, and deals with the important question of obtaining artesian water in the Kimberley district. This is a pasture

[1] Lidgerwood-Miller Marine Cableway for Coaling in a Seaway. New York: Lidgerwood Manufacturing Co., 1907.

[2] Geological Survey of Western Australia, Bulletins 23, 24, and 25. Perth, 1906.

area overlying the Carboniferous, Devonian, Silurian, and granite rock. This country is subject to annual droughts of great severity and accompanied by great heat, which are not always relieved by the wet season that is expected to begin in October. An artesian water supply is, therefore, of great importance; and the author of this report finds that in certain portions of the district success may be anticipated in the search for artesian water.

All three of these bulletins are illustrated by numerous maps, plans, and reproductions of photographs.

Beet-Sugar Manufacture[1]

The translation of the second edition of Classen's "Beet-Sugar Manufacture," by Mr. William T. Hall and Mr. George W. Rolfe, follows very closely the text of the German edition, yet the facts are forcibly expressed in a clear and concise manner. The text reads smoothly and is translated in an interesting style.

It is, however, to be regretted that some of the valuable tables in the appendix of the original volume have been omitted in this English translation; they are certainly essential and could have been very easily included.

The author is well known as an authority on beet-sugar manufacture, therefore the translation of this work will be of great assistance to the many sugar chemists who are interested in the details of the work of beet-sugar houses. L. W. P.

Chemical Reagents[2]

This volume is a translation of an extensively revised fourth edition of Krauch's well-known work, which, however, appears under the name of E. Merck as the person immediately responsible. The translator has made some modifications to bring the subject-matter more directly

[1] Beet-Sugar Manufacture. By H. Classen. New York: John Wiley & Sons.

[2] Chemical Reagents: Their Purity and Tests. By E. Merck. Translated by Henry Schenck. New York: Van Nostrand, 1907. 250 + 7 pp. $1.50 net.

into line with American practice. This applies particularly to reagents of gravities not commonly employed abroad. The book is distinctly valuable, and probably represents, in general, as near an approach to a set of standard requirements of purity as it is practicable to lay down. It is a decided advance over the earlier editions of Krauch's work, as there is a closer approximation to quantitative limitations in the tests. It is convenient in form, well printed and indexed, and is a timely addition to chemical literature, since, as the translator points out in the preface, with a suggestion of sarcasm, the report of the Committee of the American Chemical Society covering this field is likely to require a long time for its completion, judging from present progress.

H. P. TALBOT.

STREET RAILWAYS AS INVESTMENTS [1]

THIS book affords the fullest information in regard to the street and interurban railways of the United States, the Insular Possessions, Canada, and Cuba obtainable outside of the regular reports of the various companies. It contains summaries of the annual reports of the companies and a few general tables which show the growth in gross receipts of the entire industry. Among the excellent features of the publication are the maps which it contains, forty-four in number, showing the systems and more important connections of forty-seven separate companies. The general form of this work is the same as in previous years, but each year adds something to its bulk as new roads are built and old roads increase in length of line and volume of business.

In reading the tables one is struck by the steady tendency, year after year, toward larger systems and increased gross earnings. Thus in 1902 there were only thirty-eight companies with gross receipts of $1,000,000 or more, while in 1906 the number in that class was sixty-three. During this same period of five years the total gross receipts of this group increased from $159,336,273 to $275,245,406. The number of companies in this class is significant as indicating a constant tendency toward consolidation. But there has been, also, a large increase in the total number of companies of all sizes and in the total gross

[1] American Street Railway Investments. An Annual Supplement to the Street Railway Journal. Vol. XIV. New York: McGraw Publishing Co., 1907. 54 + 453 pp., 4to.

receipts of the entire industry. There were 437 companies in 1905, with gross receipts of $25,000 or more, and 481 in 1906.

It is noteworthy that the information afforded by the annual reports of the companies is more nearly adequate for the purposes of the investor than in former years. In many cases fairly complete and detailed operating statistics are given, and the matter of plant and equipment is not entirely ignored.

Another important item of information for the investor is the number of people served by a street railway. A mere statement of the population of a place is an imperfect guide at best in this matter, but when "estimates" or "local estimates" are given, as they are in many places in this publication, they should be viewed with a very critical eye. It is well known that such estimates are always unduly optimistic, and the figures given in connection with many street railway reports are even extraordinarily optimistic in character. One is naturally surprised to find that in most cases there has been apparently a greater total increase in population in the five years following 1900 than in the previous decade as given by the census returns. In some cases cities that were going backward before 1900 show a substantial increase in population since that time.

On the whole, however, the work seems to be as complete and reliable as one could expect in view of the immense growth of the industry and the evident inadequacy of the returns made by many of the companies. C. W. D.

A Handbook for the Chemist[1]

This volume of 472 pages, which from its origin might be taken to be merely an advertising catalogue of a large manufacturer, merits more than passing mention and seems to have fairly earned its somewhat ambitious title.

It is actually an encyclopedia of extraordinary compactness and completeness, stating, to quote from its title-page, "names and synonyms; source or origin; chemical nature and formulas, physical form, appearance, and properties; melting and boiling points; solubilities;

[1] Merck's 1907 Index. An Encyclopedia for the Chemist, Pharmacist, and Physician. New York: Merck & Co., 1907.

specific gravities and methods of testing; physiological effects; therapeutic uses; modes of administration; ordinary and maximum doses; incompatibles; antidotes; special cautions; hints on keeping and handling, etc., of the chemicals and drugs used in chemistry, medicine, and the arts," to the extent this information has important bearing on the characteristics and uses of the substance.

Many compounded reagents, such as Fehling Solution and Millon's Reagent, are likewise described. No prices are given, but an ingenious comparative evaluation scale is used.

The book deserves notice as a valuable ready reference work, remarkable for the amount of useful information compacted in such moderate space. GEORGE W. ROLFE.

STANDARD POLYPHASE APPARATUS AND SYSTEMS[1]

THE fifth edition of this well-known book is a new edition in fact as well as in name. Not only are there 100 more pages than in the fourth edition, but the contents have everywhere been subjected to a careful revision which has brought it thoroughly up to date.

The author has largely rewritten and expanded the text, thereby gaining in clearness of expression and in fullness of explanation, the latter point being one in which previous editions left something to be desired.

For some of the old illustrations new ones have been substituted, with considerable advantage to the appearance of the book as well as from the more important standpoint of illustrating the text.

As the author frankly admitted in the preface to the first edition, the treatment of the subject is essentially descriptive rather than analytical in character. The various pieces of apparatus are on the whole regarded as units, and the characteristics of different types are compared from the standpoint of the user rather than from that of the designer. We are not told, for example, how, given certain detailed information as to the construction of a machine, to compute its probable performance, but that with modern commercial machines such and such results can be secured.

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[1] Standard Polyphase Apparatus and Systems. By Maurice A. Oudin. New York: Van Nostrand.

As regards specific changes, the material which was formerly covered in a single chapter with the title, "Station Equipment and General Apparatus," has been rearranged in three chapters under the headings: "Motor Generators, Frequency Changers, and Other Converting Apparatus," "Switchboards and Station Equipment," and "Lightning Protection and Line Construction." In these much new matter has been incorporated, as, for example, the description of the mercury rectifier. A discussion of the new single-phase motors has also been added to the chapters on the induction motor, and the little used monocyclic system has been compressed from a whole chapter into the limits of a single paragraph.

The omission of the report of the Committee on Standardization of the American Institute of Electrical Engineers is doubtless due to the fact that at the time the book went to press the committee was preparing a new report. This has since been issued, and it is to be hoped that it will be added as an appendix in subsequent printings.

It is unfortunate that in bringing out this edition advantage was not taken of the opportunity to substitute the usual notation, which has now been recommended by the Standardization Committee of the American Institute of Electrical Engineers, for the special one employed by the author. In the case of students one of the greatest difficulties arising in the assignment of collateral reading is the confusion resulting from a lack of uniformity in notation, and it seems rather unnecessary, for example, to use the symbols S and U for reactance and impedance instead of the more general x and Z. These being simple cases, it is of less consequence than it would be in a more mathematical treatise, and, in fact, the chief value of the book to students of electrical engineering is as a supplement to more theoretical lecture courses. It is admirably adapted for the use of mechanical engineers and other persons wishing to secure information concerning the general characteristics and uses of polyphase apparatus and systems. C. H. P.

PUBLICATIONS OF THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS

"ON the Art of Cutting Metals," by Frederick W. Taylor, M.E. Sc.D., which was the presidential address presented at the last annual meeting

of the American Society of Mechanical Engineers, has been reprinted and bound by the Society; price, $3.00. This, or any other publication of the Society, may be had by addressing the Secretary, 29 West Thirty-ninth Street, New York. It is not necessary to send orders through members. None of the publications of the American Society of Mechanical Engineers are copyrighted.

PUBLICATIONS[1]

Biology, and Sanitary Research Laboratory and Sewage Experiment Station

C.-E. A. Winslow.—Disposal of Sewage. Paper read at the Ninth Annual School for Instruction of Health Officers, Burlington, Vt., June 19, 1907. *Bulletin, Vermont State Board of Health,* Vol. VIII, pp. 3–12. September, 1907.*

C.-E. A. Winslow.—Public Health and Safety. Review of Legislation, 1906. New York State Library: *Legislation Bulletin,* No. 33, pp. 45–54. August, 1907.*

Chemistry and Chemical Engineering

Arthur A. Blanchard.—Inorganic Preparations. Laboratory Exercises in the Chemistry of the Metallic Elements. Printed for the use of students of Massachusetts Institute of Technology. 80 pp. 1907.

This set of notes was designed to serve as a guide for laboratory work and study in Inorganic Chemistry during the second term of the first year at the Institute of Technology.

It had been felt for some time that qualitative analysis, which had previously been made the basis for laboratory practice during that period, did not fully meet the requirements, and that a course based upon the actual preparation of typical chemical substances might prove more satisfactory, at least for those students whose later work would be largely chemical, and that it would afford ample practice in analysis.

The general purpose of laboratory practice during the first year is to supplement the lectures on inorganic chemistry: first, in giving as broad a conception as possible of chemical processes, their nature, and the simple laws governing them; and, second, to awaken in the student a keen, scientific interest and a spirit of investigation.

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[1] In order that the extent of productive work carried on at the Institute may be better known, it is designed to publish quarterly a list of the publications of officers of the Institute, together with abstracts when possible. In this list the publications are arranged alphabetically by departments and then alphabetically by authors.

The asterisk after the title indicates that a copy of the publication has been placed in the library of the Institute.

Thus the work in the laboratory is to furnish actual experimental experiences in such a way that the student may have something tangible to which to attach his conceptions of chemical facts and principles. To accomplish this, the work must be so planned that it cannot become a mechanical following of instructions, but will be an incentive to study.

The matter of the *technique* of qualitative analysis, or of preparation work, although of very great importance, is quite secondary to the purpose herein outlined.

The plan of the notes for this course is, briefly, as follows:

Nearly all of the preparations selected are of real industrial importance, and for the starting point of each either natural products or crude industrial materials are used, so far as is possible. The course does not aim to be an exhaustive one in chemical preparations; but a limited number of exercises are selected to illustrate the most important types of compounds of the common elements and the most important methods used. The number of exercises furnished is more than any one student will be able to complete in the time allotted; thus all students may not have the same preparations.

The notes for each exercise are divided into three parts:

I. A discussion of the object of the exercise, with an outline of the method and the reasons for the steps involved.

II. Concise working directions, which, if carefully followed, should lead to obtaining a satisfactory product.

III. Questions for study which involve additional laboratory experiments, the consulting of standard text-books kept on the table in the laboratory, and original reasoning.

At the end of each group of exercises is furnished a set of general study questions, which every student is expected to work out irrespective of which of the specific exercises he has performed.

Henry Fay.—Tellurium-Tin Alloys. *Journal American Chemical Society*, Vol. XXIX, pp. 1265–1268.*

Henry Fay.—Determination of Sulphur in Pyrite. *Technology Quarterly*, Vol. XX, No. 1, pp. 27–35. March, 1907.*

Augustus H. Gill.—A Comparison of Apparatus for Testing the Liability of Oils to Produce Spontaneous Combustion. *Journal of the Society of Chemical Industry*, Vol. XXVI, p. 185. March, 1907.*

The two sets of apparatus that have been proposed for this purpose are the Ordway, described by Mrs. Richards,[1] and the Mackey.[2] The former uses fifty grams of oil and an equal quantity of cotton waste heated in an air bath to 105°, the latter fourteen grams oil on half its weight of absorbent cotton heated vertically in a water bath.

[1] This journal, 4, 346.

[2] Journal of the Society of Chemical Industry, 15, 90.

Besides these, a third apparatus was constructed on the Ordway plan, using a water bath heated under pressure to fifteen pounds and drawing a current of air through it at a definite ratio.

The difficulty with the apparatus first described and made (Ordway's) was that results could not be as easily and accurately duplicated on account of the method of heating. As a result of a series of experiments with different oils, it was found that Mackey's apparatus gave the most concordant and satisfactory results.

Augustus H. Gill.—Engine Room Chemistry. A Compend for the Engineer and the Engineman. New York: Hill Publishing Co., 1907. 187 pp., 47 il., 8vo.*

Augustus H. Gill and *Charles R. Haynes.*—The Probable Efficiency of Accidental Gas Explosions. *Journal American Chemical Society,* Vol. XXIX, pp. 1482–1488. October, 1907.*

Experiments were made with various sized boxes, from 1 to 8 cubic feet capacity and various depths from 1 to 4 feet, with explosive mixtures of air and illuminating gas. The results showed an efficiency of one hundredth of 1 per cent. when the lid was fitted *upon* the box, and of ten times that amount where it fitted *into* the box. This was due to the fact that the lid had to be raised by its own thickness before the box could be vented. These results agree well with those obtained by Dr. Gill and a colleague, each working independently, with some fifty explosions in cavities or boxes from 80 to 7,000 cubic feet capacity.

The efficiency seems to increase if the point of ignition be near the bottom rather than near the top.

Arthur A. Noyes.—The Electrical Conductivity of Aqueous Solutions. Carnegie Institution: *Publication No. 63,* September, 1907. 352 pp., 20 il., 8vo.*

A. G. Woodman and *H. P. Talbot.*—The Fluorine Content of Malt Liquors. *Journal American Chemical Society,* Vol. XXIX, pp. 1362–1366. September, 1907.*

The authors have made determinations of the fluoride content of a number of samples of commercial malt liquors and of brewing materials. About fifty brands, both foreign and domestic, were examined, and samples of brewing sugars, malt, barley, yeast, and waters were tested. The method used was the one described in a previous paper.[1] The results obtained show that the presence of a slight amount of fluoride in malt liquors is the rule rather than the exception, and that this fluoride is derived principally from the malt.

One part of fluorine in 100,000 (10 mgs. per liter) is suggested as the maximum limit of permissible fluoride in malt liquors.

[1] Journal American Chemical Society, 28, 1437.

Drawing and Descriptive Geometry

Charles L. Adams.—Descriptive Geometry, Part 1. Second edition, enlarged. Boston, October 31, 1907. 161 pp., 255 il., 8vo.

Electrical Engineering

Dugald C. Jackson.—Methods of Electric Lighting for Railway Trains. *Journal of Western Society of Engineers,* Vol. XII, 30 pp. May 15, 1907.*

Dugald C. Jackson.—The Relations of the Engineering Schools to Polytechnic Industrial Education. Presidential Address. *Proceedings of Society for the Promotion of Engineering Education,* Vol. XII, July 2, 1907, and *Science,* N. S., Vol. XXVI, No. 656, July 26, 1907, pp. 104–111.*

Charles H. Porter.—Notation for Polyphase Circuits. *Electric Journal,* Pittsburg, Vol. IV, 9 pp., 7 il. September, 1907.*

George C. Shaad.—Loading Stationary Induction Apparatus. *Electric Journal,* Pittsburg, Vol. IV, pp. 346–351, 5 il. June, 1907.*

English

Allen French.—The Book of Vegetables. New York: Macmillan, April, 1907. 312 pp., 152 il., 12mo.

Geology

H. W. Shimer.—An Almost Complete Specimen of *Strenuella strenua* (Billings). *American Journal of Science,* Vol. XXIII, pp. 199–201. March, 1907. Addendum in April number, p. 319, 2 il.*

Discusses a specimen of this species from Mill Cove, North Weymouth, Mass. The specimen is the most complete yet published and the only one in which an identifiable cephalon is united to the thorax.

H. W. Shimer.—A Lower-Middle Cambrian Transition Fauna from Braintree, Mass. *American Journal of Science,* Vol. XXIV, pp. 176–178, il. August, 1907.*

Discusses the occurrences of five species of fossils characteristic of the middle Cambrian and two of the lower Cambrian from a single large slate bowlder. The bowlder was found in East Braintree, Mass., by Mr. T. A. Watson. This lower-middle Cambrian transition fauna is the first recorded from this region. A description of the individual species is also given.

History and Economics

Davis R. Dewey.—Financial History of the United States. Third edition. Longmans, Green & Co., September, 1907. 350 pp.

Mathematics

H. E. Slaught and *N. J. Lennes.*—High School Algebra. Elementary Course. Boston: Alleyn & Bacon, June, 1907. 12 + 297 pp., il., 12mo.*

Edwin Bidwell Wilson.—Oblique Reflections and Unimodular Strains. *Transactions of the American Mathematical Society,* Vol. VIII, pp. 270–298. April, 1907.*

Is a continuation of the author's earlier investigations on the relation between the projective group (or its subgroups) and the involutory transformations of that group (or its subgroups). The problem of the present paper is to discuss the resolution of unimodular strains in three-dimensional space into the product of oblique linear or planar reflections. The necessary and sufficient conditions are determined for the resolution of a strain into two reflections, and an extended geometric discussion is given for all cases in which such resolution is possible.

Further, it is shown that any unimodular strain may be resolved into the product of three reflections and the method of accomplishing the resolution is indicated. The investigation is carried on by means of vector analysis. This enables the main geometric results to be stated as theorems in the algebra of matrices.

Edwin Bidwell Wilson.—The Revolution of a Dark Particle about a Luminous Centre. *Annals of Mathematics,* Second Series, Vol. VIII, pp. 135–148. April, 1907.*

This paper is a mathematical treatment of some of the questions taken up by Poynting in *Nature,* November 22, 1906. It is shown that the total number of revolutions which such a particle can make about a radiating centre of force obeying the Newtonian law is finite. The approximate solution for the path may be obtained by expanding the Bessel's functions which occur in the solution into the customary trigonometric-power series. In this way the amount of fall toward the centre per revolution, the change in the eccentricity of the approximately elliptic path, and the amount of advance of the apse of that path per revolution may all be obtained. The mathematical investigation, therefore, demonstrates the existence of certain phenomena and determines them quantitatively, whereas without that investigation it is difficult to indicate them even qualitatively.

Mining Engineering and Metallurgy

H. O. Hofman.—Review of C. Schnabel and H. Louis's Handbook of Metallurgy. London and New York: Macmillan. 2 vols., 1905 and 1907. *American Chemical Journal,* 1906, Vol. XXXV, p. 473; 1907, Vol. XXXVIII, p. 379.

H. O. Hofman.—Review of O. Hofmann's Hydrometallurgy of Silver. New York: Hill Publishing Co., 1907. *Journal American Chemical Society,* Vol. XXIX, p. 1246. 1907.

H. O. Hofman.—Recent Improvements in Lead Smelting. *Mineral Industry,* Vol. XV, p. 522. 1907.

Robert H. Richards.—Wilfley Table.[1] *Transactions of the American Institute of Mining Engineers,* July, 1907.*

Robert H. Richards.—Velocity of Galena and Quartz in Falling Water. *American Institute of Mining Engineers,* April, 1907.

Robert H. Richards.—The Advances in Ore Dressing in the Last Decade. *Mineral Industry,* Vol. XV, pp. 807–809. 1907.

Robert H. Richards and *D. T. Day.*—Useful Minerals in the Black Sands of the Pacific Slope. United States Geological Survey, *Mineral Resources of the United States* for 1905, pp. 1175–1258. 1906.

Robert H. Richards and *C. E. Locke.*—Progress in Gold Milling in 1906. *Mineral Industry,* Vol. XV, pp. 391–402. 1907.

Robert H. Richards and *C. E. Locke.*—Progress in Ore Dressing and Coal Washing in 1906. *Mineral Industry,* Vol. XV, pp. 810–865. 1907.

Naval Architecture

Harold A. Everett.—Glimpses into Some German Shipyards. *International Marine Engineering,* Vol. XII, pp. 286 and 306. July and August, 1907.

Commander William Hovgaard, R.D.N.—On the Speed of Battleships. *Transactions of Society of Naval Architects and Marine Engineers,* Vol. XV. New York, 1907. (Read at the International Congress of Naval Architecture held in Bordeaux, France, June 25, 26, 27, 1907.)

This paper contains an analysis of the means and methods by which a speed increase can be realized in battleships. The following are the main features discussed in the paper:

1. Increase in the percentage weight of displacement allotted to machinery.

[1] Reprinted in full above, pp. 453–478.

2. Increase in size, preserving geometrical similarity in form of hull.
3. Increase in the scales of length, beam, and draught.
4. Increase in fineness.
5. Improvements in propulsive machinery.
6. Influence of speed on free-board, height of geer-axis, and beam.
7. Speed and strength of hull.
8. Speed and hold space.

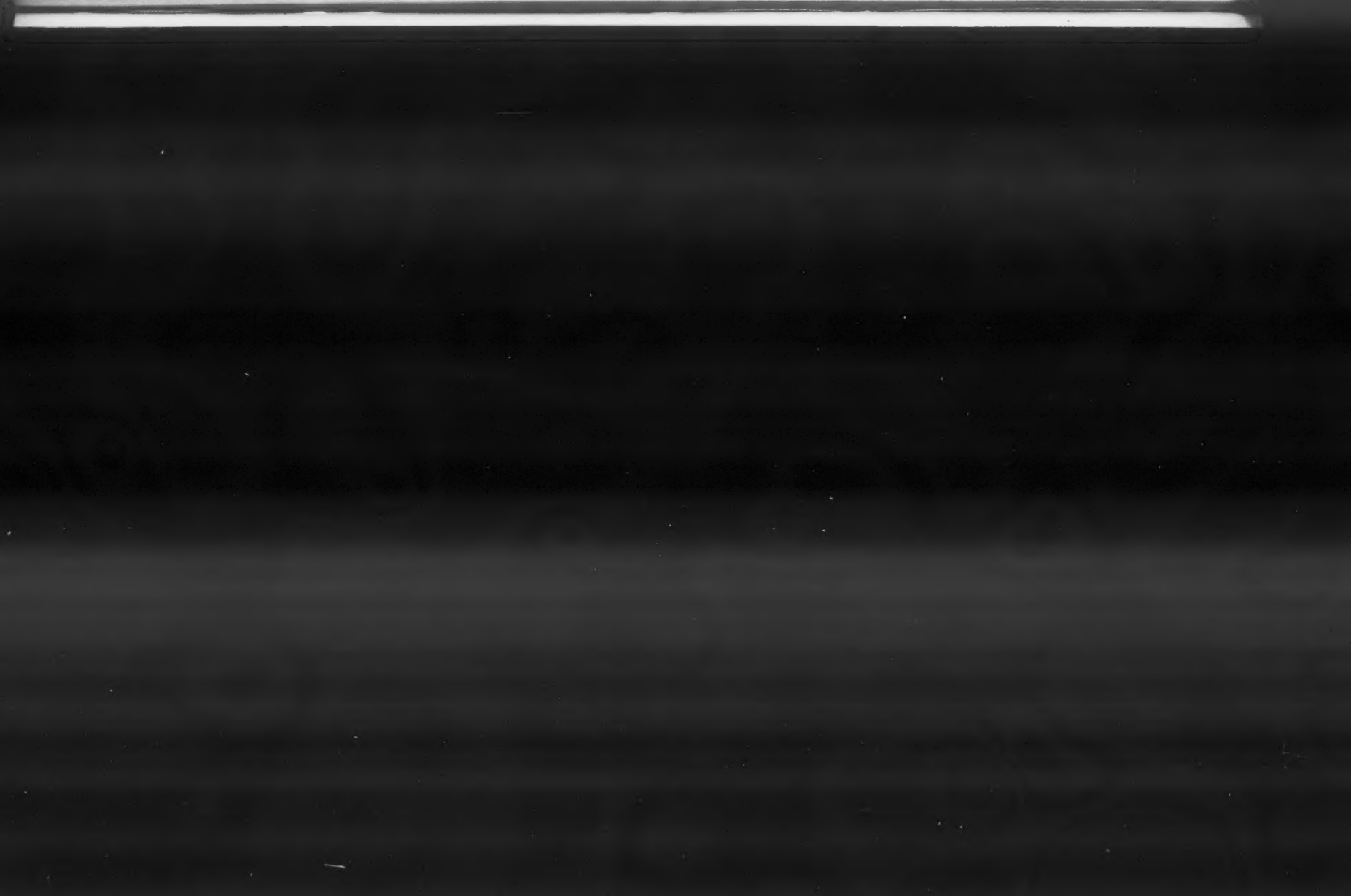
Conclusion.—The only legitimate method of obtaining a considerable increase of speed is by technical improvements which permit greater power to be developed on a given weight of machinery and fuel. In order to derive full benefit from the increased power, changes must, however, be made in the form of hull, involving primarily an increase in length and fineness. These changes should be accompanied by an increase in beam and free-board.

Since such changes will in all cases involve an increase in hull and armor weight, we must, if it is desired to carry a certain battery and a certain corresponding system of protection, also increase the displacement.

An example is worked out on basis of the design of the United States battleship *Connecticut.*

Institute Publications

Massachusetts Institute of Technology. *Bulletin*, Vol. XLII, No. 4, Programme. Boston, June, 1907.*



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TECHNOLOGY QUARTERLY

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SOCIETY OF ARTS

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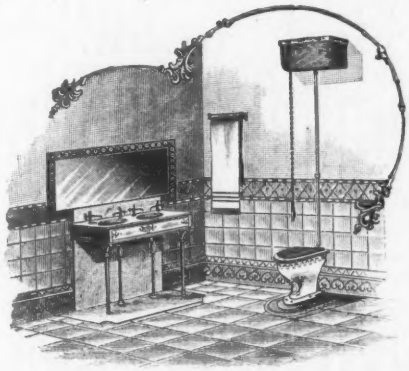

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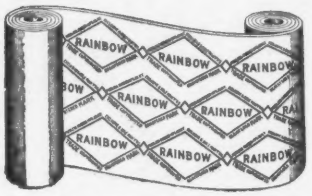

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